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The Geology of the Hangman Grits of the Quantock Hills.

By A. D. Hallam, B.A., B.Sc., F.G.S.

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I. Introduction.

THE Hangman Grits of the Quantocks consist of a series of sandstones, now, in most instances, practically converted into quartzites by the great pressure to which they were subjected during the Armorican movements, and occasional shales, which sometimes show cleavage. There are also beds, never of any great thickness, which bear a strong resemblance to the Keuper Marls. Fossils, other than a few obscure plant-remains, are unknown, except in the beds which are usually regarded as forming the top of the series, where marine fossils occur as casts in what is evidently a decalcified calcareous sandstone.

Comparatively little attention has been paid to the arenaceous formations of the Devonian of North Devon and West Somerset, chiefly owing to the great scarcity of fossils; but an attempt was made by Payne in 1854 (6) [1] to divide up the Hangman Grits of the Quantocks. In Pring's section appended to this paper the northernmost beds of the Quantocks are marked as Lynton Beds. The late W. A. E. Ussher (14, 15) discussed the possibility of the beds on the northern part of the Quantocks in Smith's Combe and at Perry belonging to the Foreland Sandstones. However, owing to lack of exposures, he was not able to follow this up. (See also 13, pp. 10–12.)

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[1] The numbers in parentheses refer to Bibliography at end of article.

Nobody seems to have noticed the peculiar character of the strata found at Triscombe, Halsway and elsewhere, perhaps because the quarries, now being actively worked for road-metal, were not so extensive in those days. Any correlation attempted was done by the inspection of hand-specimens alone.

At Holford Ussher and Hamling discovered fossiliferous strata, which they correlated with similar deposits found on Great Hangman on Exmoor (16), and in 1872 the late H. H. Winwood found a specimen of *Petraia* in a quarry nearby. Another fossil-locality was recently discovered by the writer at Friarn, near Over Stowey.

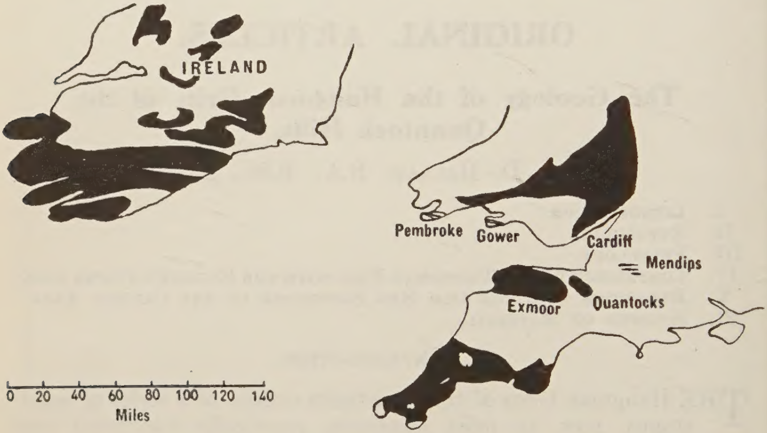

FIG. 1.—Sketch-map showing the distribution of the Devonian and Old Red Sandstone in South-West England, South Wales, and Southern Ireland.

The late Dr. J. W. Evans (3) divided the Hangman Grits of Exmoor into three series:—

3. Sherry Combe Beds with *Cucullaea unilateralis* J. de C. Sow., var. *angusta* Phill., a *Myalina* allied to Upper Devonian forms, *Spathella munda* Whidb. ?, *Naticopsis* sp., *Spirifer* sp.
2. Rawn's Beds: alternations of gritty and shaly beds "representing apparently successive flood-deposits".
1. Trentishoe Grits: uniform fine-grained red sandstones, with no fossils.

He does not mention any equivalent of the Trentishoe Grits on the Quantocks; but he correlates the Rawn's Beds with the sandstones and shales of the northern end of the Quantocks on the strength of the occurrence of certain rather indefinite plant-remains. He follows Ussher and Hamling in identifying the fossiliferous beds of Holford with those of Great Hangman, which he calls the "Sherry Combe Beds".

II. Exposures.

The majority of exposures occur either as quarries, few in number, and situated chiefly on the borders of the range, or in the beds of streams, generally near the source. Altogether about eighty exposures were noticed; but practically all, including the quarries, which were in many cases small, were of little assistance in determining the structure and succession, as often only a few feet were exposed at a time, and very few of the exposures in the stream-beds furnished any indication of the amount or direction of dip. With regard to the fossil-beds, which, one would have thought at first sight, might have been of some use in elucidating the stratigraphy, the faunas of these proved to be very dissimilar. The Holford exposure yielded nothing but casts of lamellibranchs and gastropods, though Ussher records the finding of a specimen of *Spirifer* (13, p. 9), while the strata at Friarn provided only brachiopods, corals and crinoid-ossicles,

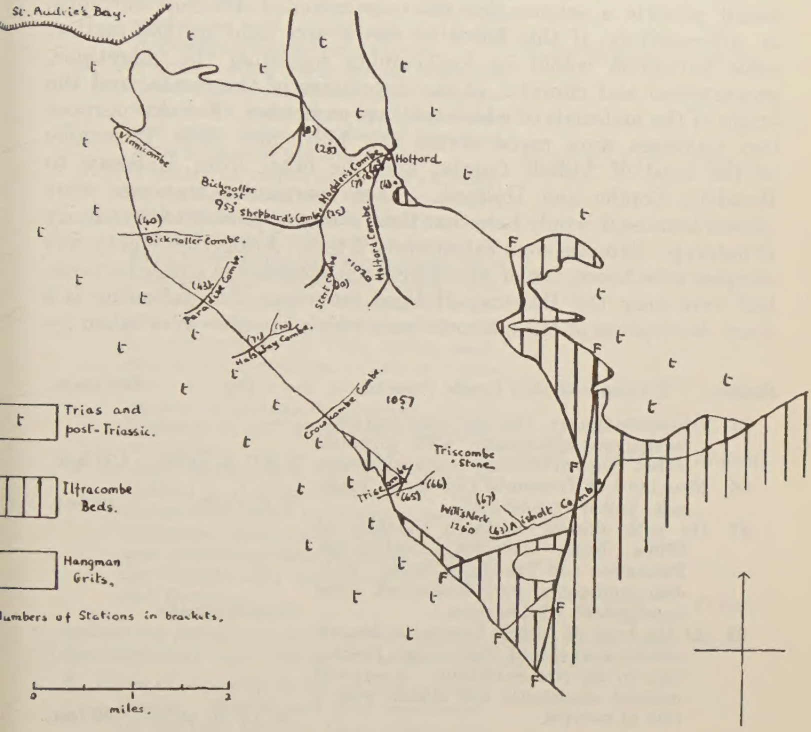

Fig. 2.—Sketch-map of the Geology of the North-Western end of the Quantock Hills. (After Ussher.)

all in an exceedingly fragmentary state, and perhaps not belonging to the Hangman Grits at all. For this reason it was not considered safe, in the present state of knowledge, to treat them as if they belonged to the same horizon. Thus the complexity of structure, the rarity of exposures, due to the thick and almost universal covering of vegetation and head, and the dissimilarity of the faunas in the two fossil-beds all combined to make the elucidation of the detailed stratigraphy a matter of great difficulty. It was therefore decided to attack the problem by concentrating on the petrology of the sandstones, in the hope that differences in their composition would provide a scheme for the correlation of different outcrops, or, alternatively, if this failed to throw any light on the matter, some indication would be forthcoming regarding the conditions, geographical and climatic, of the deposition of the strata, and the origin of the materials of which they are composed. For this purpose two traverses were made across the hills, one from Triscombe to the head of Aisholt Combe, and the other from Halsway to Hodder's Combe and Holford. These particular traverses were chosen because it is only here that there is any approach to continuity of outcrop. Samples were taken every 5 feet. Altogether eighty-five samples were taken, ten of which were not included in either traverse, but were near the Halsway–Holford traverse. The following is a short description of the stations from which samples were taken :—

Station.	*Triscombe–Aisholt Combe Traverse.*	*Dip.*	*Thickness.*
65	Triscombe Quarry. Greenish-grey and grey sandstones alternating with greenish slates. Some of the sandstones calcareous.	N. 67° E. at 28°.	150 feet.
66	Near head of Triscombe Combe, by roadside. Soft red sandstones.	N.E. at 25°.	10 feet.
67	On path skirting northern shoulder of Will's Neck, between Bagborough Plantation and Triscombe Stone. Reddish sandstones, very weathered, some impregnated with barytes.	Indeterminate.	
63	At the head of Aisholt Combe, in branch nearest west side of Bagborough Plantation, in dry stream-channel. A series of mottled sandstones and shales, with a vein of barytes.	N. 72° E. at 25°.	30 feet.
	Halsway–Holford Traverse.		
71	Halsway Quarry. Greenish-grey and grey sandstones, some calcareous, alternating with greenish slates.	S. 77° W. at 23°.	130 feet.
70	Series of exposures in stream-bed in left-hand branch of Halsway Combe. Beds similar to 71.	S. 82° W. at 48°.	
20	Series of exposures in stream-beds in Stert Combe (right-hand branch of Hodder's Combe). Hard, compact grey and purple sandstones, with purple shales.	Indeterminate.	

Station.	*Triscombe–Aisholt Combe Traverse.*	*Dip.*	*Thickness.*
25	In Hodder's Combe, just below junction of Shepperd's Combe with Somerton Combe. Compact grey sandstones with marly parting, followed by purple sandstones.	N. 2° E. at 33°.	15 feet.
7	Quarry opposite Round House in Hodder's Combe, on right-hand side. Thick-bedded and well-jointed sandstones, red, and grey with specks of haematite, with an occasional shaly parting. The sandstones contain pebbles at the base and also at about 15 feet up. Micaceous sandstones and sandstones containing fragments of felspar are frequent.	N. 67° E. at 19°.	60 feet.
6	Old quarry a few yards further down the Combe, also on right-hand side. Alternation of thin red and mottled sandstones and green shales, the former becoming more micaceous towards the top.	N. 30° E. at 41°.	50 feet.
5	Old quarry at mouth of Hodder's Combe, on the right-hand side. Grey sandstones with specks of haematite, 8 feet exposed, base not seen. Upper surface appears to have been eroded and the hollows filled with grey and red-stained shales. The sandstone appears to be replaced laterally by shales. The shales are followed by alternations of thin, fissile sandstones and red shales. Casts of fossils occur in the lower sandstone. Only remains of gastropods observed. H. H. Winwood in 1872 discovered a specimen of *Petraia*.	N. 62° E. at 28°.	20 feet.
4	In lane leading from Old Post Office at Holford to Holford–Stowey road. Grey shales with three impersistent beds of sandstone, impregnated with haematite and containing casts of fossils. This is the fossil-locality discovered by Ussher and Hamling.	N. 34° E. at 26°.	17 feet.

Stations not included in either of the traverses, where strata occur which Ussher considered might belong to the Foreland Grits (14, 15).

8	Series of exposures in stream-bed in Den's Combe. Mottled and grey sandstones. On the spur between Den's Combe and Dry Combe. Red sandstones containing quartz pebbles.	N. 67° E. at 35°.	
28	Old quarry to east of Alfoxton Cottage. Grey, purple, and mottled sandstones with grey and mottled shales. There is a vein of barytes in the quarry.	N. 67° E. at 20°.	15 feet.

III. Petrology.

A. *Macroscopic.*

Macroscopically the Hangman Grits of the Quantocks can be divided into three series :—

(*a*) Grey and green fine-grained quartzitic sandstones, some beds of which are calcareous, and greenish slates. These beds occur at Triscombe (station 65), Crowcombe Combe (45), Halsway Combe (70, 71), Paradise Combe (43), Vinnicombe.

(*b*) Red, purple, and mottled sandstones, sometimes micaceous and flaggy; with red, mottled, and greenish-white shales and marls. The argillaceous beds often have a greasy feel. These deposits occur at all stations except those referred to in series (*a*) and (*c*). The sandstones of station 7 sometimes contain grains of felspar. Thin beds of conglomerate occur at stations 7 and 40 (Bicknoller Quarry). Sandstones with occasional quartz pebbles are more frequent. Marl-pellets are often met with in the sandstones.

(*c*) A series of sandstones passing laterally into shales. The sandstones contain casts of lamellibranchs and gastropods and, especially at station 4, are impregnated with haematite. These beds occur at stations 4 and 5.

The first series (*a*) will be known hereafter as the " Triscombe Beds " and the second as the " Hodder's Combe Beds ". There is little doubt that series (*c*) corresponds to Evans's " Sherry Combe Beds ", so that that name will be retained for the fossiliferous beds at Holford; but as regards the Triscombe Beds and the Hodder's Combe Beds we cannot say how far they correspond with the Trentishoe Grits and Rawn's Beds of Exmoor, so that it is best, in the present circumstances, not to use Evans's classification, which he himself admits to be tentative, except for the Sherry Combe Beds. On the Quantocks argillaceous beds occur at intervals throughout, though they are subordinate to the sandstones and perhaps rarest in the Hodder's Combe Beds, which Evans correlated with the Rawn's Beds of Exmoor. Evans makes no mention of strata on Exmoor or the Quantocks resembling the Triscombe Beds.

B. *Microscopic.*

The samples collected were crushed and separated with bromoform, Professor Sollas's pattern of separator being used. The yield of heavy minerals was usually small.

LIST OF HEAVY MINERALS.

Zircon.
Tourmaline.
Rutile.
Apatite.
Muscovite.
Chlorite.
Barytes.
Anatase.
Magnetite.
Ilmenite.
Leucoxene.
Pyrite.

Remarks.

Zircon.

There are two main classes:—

1. Rounded grains and prisms with a granular surface.

2. Idiomorphic crystals, the faces of which are quite fresh and the edges unrounded.

On the whole the rounded grains predominate. The majority of these are colourless, but some have a tinge of yellowish-brown, and occasionally grains with a definite purple tint are met with. The idiomorphic crystals are practically always colourless.

Tourmaline.

Yellowish-brown ; purple-brown ; grey, sometimes with a greenish tint ; blue. It generally occurs in the form of rounded grains, but the grey variety is sometimes idiomorphic and tends to occur in laths. It is usually highly pleochroic. The yellowish-brown and grey varieties occur throughout, but the purplish-brown is most frequent in the Triscombe Beds. The blue type is always rare, but is found in each of the three series.

Rutile.

Fox-red and yellowish-brown. It generally occurs in the form of rounded grains and prisms. Polysynthetic twinning is common, but only one or two examples of the geniculate form of twinning were noticed. It is occasionally found in the sagenitic habit in muscovite. It occurs throughout.

Apatite.

Occurs throughout in rounded grains.

Muscovite.

Occurs in varying quantities throughout.

Chlorite.

Occurs in green flakes, often with a very low birefringence. It has only been found in the Triscombe Beds, where it is abundant.

Barytes.

Always occurs as large, irregular fragments, and in the neighbourhood of veins of the same. It is probably of secondary origin. It has been found as a cement in the Triassic sands in the neighbourhood by Dr. H. H. Thomas (13, p. 62). In the Hangman Grits it is confined to stations 63 and 28.

Anatase.

Occurs in a tabular habit with bipyramid and basal pinacoid. It is exceedingly rare, only one or two crystals having been found. It is pale brown in colour. The crystals are quite undamaged and the mineral is here probably authigenic.

Opaque Minerals.

Leucoxene is the most abundant and occurs throughout. Magnetite, except in one or two instances, is not common. In the Triscombe Beds an occasional grain of pyrite has been noticed.

Light Minerals.

These comprise quartz, chert, and felspar, with occasional fragments of micropegmatite and schistose material. The quartz, in most cases, exhibits a wavy extinction between crossed nicols. Fluid lacunae, often with gas-bubbles, and frequently arranged in lines, are common. This feature, according to Dr. Mackie (17), is especially characteristic of quartz from granite, quartz-diorite, and related rocks, and also from quartz-veins.

The felspar from station 7 in the Hodder's Combe Beds consists entirely of orthoclase with a little microcline. In the Triscombe Beds plagioclase of a composition near that of oligoclase occurs, but is never common.

IV. Comparison of the Triscombe Beds and the Hodder's Combe Beds.

The presence of calcareous beds in the Triscombe Beds is one of the most striking differences between them and the Hodder's Combe Beds. Examination of thin sections shows that the calcite occurs in the form of grains mixed up with the other constituents, and was therefore most probably deposited at the same time as they were. There are, however, no traces of fossils, so that either the calcite was derived from older limestones or was deposited chemically. Unfortunately the rocks have been so much distorted by earth-movements that it is difficult to tell what was the appearance of the calcite when it was deposited.

Besides the exclusive occurrence of chlorite and calcite in the Triscombe Beds there is another difference between them and the Hodder's Combe Beds—a difference which may give some clue to the conditions of deposition. As we have pointed out, the Hodder's Combe Beds are of a predominantly red colour, due to the presence of anhydrous ferric oxide. The Triscombe Beds, on the other hand, are green and grey. That they contain iron is shown by the abundant haematite on the weathered surfaces. Chemical tests show, however, that the iron in the unweathered rock is partly in the ferrous state. Now, as G. E. Dorsey (2) has pointed out, ferrous oxide, the presence of which in rocks gives rise to a green coloration, is relatively unstable, being easily changed to the ferric state under ordinary weathering conditions, unless reducing agents are present. The presence of relatively abundant ferrous iron in the Triscombe Beds implies, therefore, the presence of reducing agents in them at the time of deposition. The commonest reducing agent in Nature is hydrogen sulphide, a substance produced by the decay of organic matter. The suggestion that this substance, and hence the presence of organic matter, was responsible for the reduction of the ferric oxide (or for inhibiting the oxidation of ferrous iron) may perhaps be supported by the occurrence of a little pyrite in the Triscombe Beds. None has been observed in the Hodder's Combe Beds. The occurrence of calcite in the Triscombe Beds may also point to the former presence of organic matter in them ; but there are, as we have already pointed out, no traces of fossils. However, whether the calcite can be connected with the presence of ferrous iron or not, it is evident that the Triscombe Beds were laid down under different conditions from those which controlled the deposition of the Hodder's Combe Beds.

The order of superposition of the Hodder's Combe Beds and the Triscombe Beds is doubtful ; but since the mineralogical composition of the former is the same as that of the Sherry Combe Beds there is good reason to suppose that they come next to them. It is generally thought, though the evidence is not absolutely conclusive, that the Sherry Combe Beds immediately precede the Ilfracombe Beds. Now the latter are truly marine, the Sherry Combe Beds are considered to be littoral (4, p. 135), and these two facts point to a deepening or encroachment of the sea ; so that we might expect the conditions represented by the Sherry Combe Beds to have been preceded by a continental and fresh-water phase. Arguments in favour of the Hodder's Combe Beds being continental are the amount of ferric oxide in the sandstones (though this, as Dorsey (2) and Raymond (7) point out, does not necessarily imply arid conditions), and the absence of marine fossils. The only organic remains found in the Hodder's Combe Beds are a fragment of *Calamites cannaeformis* and certain linear markings which are thought by some to be vegetable remains. The absence of marine fossils is, of course, negative evidence ; but abundant casts of marine organisms are found preserved in the Sherry Combe Beds, sediments of much the same character. If originally there were fossils in the Hodder's Combe Beds, why are they not preserved as they are in the Sherry Combe Beds ?

It must be mentioned, however, that, although the Hodder's Combe Beds resemble the Old Red Sandstone in some particulars, they lack two very common features of the latter—cross-bedding and ripple-marking. The bedding of the Hodder's Combe Beds is, except for one or two eroded surfaces, regular.

The Triscombe Beds, as we have shown, are quite distinct from the Hodder's Combe Beds ; but, as neither the base nor the top have been located, it cannot be said for certain whether they precede the Hodder's Combe Beds or are intercalated with them. As may be seen from the mineral content of the two series, the sediments forming them must have been derived from very similar, though not the same, sources. Considering the similarity, macroscopic and microscopic, of the Hodder's Combe Beds and the Sherry Combe Beds, and the apparent superposition of the latter on the former in Hodder's Combe, and considering the petrological differences of both from the Triscombe Beds, it seems reasonable to suppose that the order of deposition on the Quantocks was :—

3. Sherry Combe Beds.
2. Hodder's Combe Beds.
1. Triscombe Beds.

V. Relations with the Old Red Sandstone of the Cardiff Area.

It had long been supposed that in Devonian times the basin in which the Old Red Sandstone of South Wales was deposited was separated from the area in which were laid down the Devonian sediments of West Somerset and North Devon. Evans, however, considered that during Devonian times the land sloped down gently from " St. George's Land " towards the south into the Devonian sea, and that the rivers which flowed through that region entered the sea in the neighbourhood of the present south coast of the Bristol Channel. This, of course, would have the effect of bringing detritus from St. George's Land to the places where the Hangman Grits were laid down.

Research into the petrology of the Hangman Grits furnishes evidence, as far as the Hangman Grits are concerned, in favour of the former hypothesis ; for the most striking feature in the whole series is the absence of garnet. This absence has also been observed by Shannon in the Hangman Grits of Exmoor (10). Now, according to Heard and Davies, who made a petrological examination of the Old Red Sandstone of the Cardiff Area (5), garnet is common there throughout the series, and chlorite is abundant except in the upper group. For this reason there is little likelihood that there was any communication between the two areas at the time when the Hangman Grits were being deposited. From Shannon's work on Exmoor it may be seen that the two districts may have been connected during part of the Devonian, as garnet is found in the Lynton Beds, the Ilfracombe Beds, the Baggy Sandstones, and the Pilton Slates. Garnet is absent from the rest of the series, so that there must have been a barrier of some kind cutting off the area to the south of the Bristol Channel from that of South Wales. Of course, the presence of garnet in some of the Devonian rocks of North Devon and West Somerset does not necessarily imply communication with those of South Wales, as the garnet may perhaps have been derived from independent sources. Still, there is support for it as far as the Lower Pilton Beds are concerned ; for on palaeontological grounds they have been correlated with the Skrinkle Sandstones of South Wales. Nevertheless, there is strong evidence of there having been a barrier at the time when the Hangman Grits were being laid down.

The presence of a barrier implies the existence of a line of uplift running approximately east and west. Now in the Eastern Mendips there is an inlier of Silurian rocks. It has been described by Professor Reynolds (8, 9), and consists of tuffs, some fossiliferous and indicating probably a Llandovery age, andesitic lavas, and a kind of agglomerate. With regard to the relation of the Silurian to the neighbouring Old Red Sandstone Reynolds remarks that " there is no evidence of the presence of the upper horizons of the Silurian series " (8). He concludes that " it seems not unlikely that the Mendips formed part of a land area during the late Silurian and early Old Red Sandstone times" (9).

At Gower there is evidence of an unconformity of the Lower Old Red Sandstone on the Silurian, but it has not been actually proved, as no junction between the two formations has been found. There is, however, a definite unconformity in Pembrokeshire and, further, E. E. L. Dixon notices a thinning of the Lower Old Red Sandstone towards the south (1), a fact which suggests the presence of land in that direction. There is, therefore, evidence that the line of uplift, the remains of which we find on the Mendips, was continued to the west. Thus we have further evidence for the existence of a barrier.

According to Evans the Hangman Grits and their successors up to and including the Pickwell Down Sandstones were being deposited at the time when in South Wales (though possibly not in the Cardiff area) there was a long period of erosion marked by a great palaeontological break and discordance (4, p. 169). If there was erosion in South Wales, whither was the material carried ? If it had been carried to the south it would have been deposited in North Devon and West Somerset, and would, presumably, have shared in the formation of the Hangman Grits. Now all the sediments of the Old Red Sandstone of the Cardiff area were derived from garnetiferous sources: the Hangman Grits are not. In the Cardiff area there is a great palaeontological break, but apparent conformity throughout the Old Red Sandstone. If we accept the conformity we have an unbroken succession of garnetiferous sediments, at any rate, in part of the South Wales basin of deposition. If we do not accept it we cannot prove that non-garnetiferous rocks were not laid down, and afterwards eroded and carried away to form the Hangman Grits south of the Bristol Channel. If there was conformity in the Cardiff area, there must have been a barrier between the two districts. If there was not conformity the existence of a barrier can neither be proved nor disproved. If we take into consideration the petrological evidence afforded by the rest of the Devonian it can be seen that there is a much better case for the existence of a barrier than has been lately supposed.

VI. Sources of Material.

It now remains for us to inquire into the probable sources of the materials forming the Hangman Grits of the Quantocks. The material, like that forming the Old Red Sandstone of the Cardiff area, seems to have come from a mass of acid igneous or highly metamorphosed rocks. If there was a barrier the material cannot have come from the same source as that from which the sediments of the Cardiff area are supposed to have been derived, i.e. from an extension of the pre-Cambrian massif, of which the Mona Complex forms a remnant. Some of the material, at any rate, must have been derived from the south side of the barrier. and that leads us to an investigation of its probable composition. Unconformities of the Old Red Sandstone with the Silurian have been proved or inferred on the Mendips (8), at Gower (12), and in Pembroke (1). In the Cardiff area there is apparent conformity but an abrupt change in the mineralogical constitution in the Lower Old Red Sandstone. The Silurian rocks of the Mendips have already been described. Heard and Davies made an examination of those of the Cardiff area, though they admit that it is not exhaustive. They found that " the Silurian has a characteristic assemblage of minerals, which is entirely distinct from that of the Old Red Sandstone of the same area ". Concerning the Rumney (Rhymney) Grit, which has been described by Professor Sollas as " consisting of greyish mudstones passing into argillaceous sandstones " (11, p. 480), Heard and Davies (5, p. 510) make the following observations : " The zircons, on the whole, are extraordinarily uniform in type and size, being colourless and more or less ovoid, although some few idiomorphic grains are present. A few small well-rounded zircons occur, of a faint pinkish-brown colour [purple type of Dr. Mackie ?] ; but the proportion of this type to the colourless grains is very small, when compared with that seen in the Old Red Sandstone. Brown tourmaline and rutile of a deep amber colour occur, although they are distributed but sparingly through the rock, one or two grains occurring in each separation. No garnets have been observed, and apatite has not been detected with certainty, although a few intensely-clouded well-rounded grains may possibly represent altered apatite.

' The constituents of the lighter crops also present a characteristic and distinct assemblage.

" The angular and sub-angular quartz-grains are much more uniform than those of the Old Red Sandstone. No perfectly rounded grains have been observed. The quartz-grains exhibit practically no evidence of strain or regular inclusions." They conclude that " the Silurian rocks of the Cardiff district are typically sediments which have been derived from pre-existing sediments, while the greater part of the Old Red Sandstone rocks . . . were probably derived from metamorphic and igneous areas ".

The Silurian rocks of Gower and Pembroke consist chiefly of mudstones, shales, and sandstones ; but the petrology has not yet been investigated, so that we cannot tell at present whether the materials were derived from the same sources as the Silurian of the Cardiff area or not.

If sediments of the same nature as those of the Silurian of the Cardiff area contributed to the Hangman Grits of the Quantocks, they must have been entirely swamped by materials of a similar type to those found in the Old Red Sandstone of the Cardiff district. The minerals, with the notable exception of garnet, and the persistence of chlorite throughout the lower and middle groups are very much the same, though in the Hangman Grits there is not a very high proportion of coloured zircons; but still, with the unweathered felspars, the quartz showing a wavy extinction between crossed nicols, the fragments of chert, and the pebbles of vein-quartz, there is a remarkable similarity between the sediments of the two areas, which, while it cannot, as we have shown, be due to derivation from the same source, must point to derivation from very similar sources.

If communication had been cut off from the north (except, of course, with regard to the barrier itself) the materials which form the Hangman Grits must have come from the south, the east, or the west. The Devonian sea deepened towards the south, so that they cannot have been derived from that quarter. There therefore remain the east and the west. The Devonian and pre-Devonian rocks to the east are unfortunately buried beneath newer sediments, so that we are unable to draw any conclusions, and the thick deposits of Old Red Sandstone in the south-west of Ireland to the west have not been petrologically investigated, so that we are not at present able to say what connection they had, if any, with the Old Red Sandstone of the Cardiff area or the Devonian of North Devon and West Somerset.

VII. Comparative Table of Heavy Minerals.

	Triscombe Beds	Hodder's Combe Beds	Sherry Combe Beds	Hangman Grits of Exmoor (*a*)	O.R.S. Cardiff Lower Group (*b*)	O.R.S. Cardiff Middle Group (*b*)	O.R.S. Cardiff Upper Group (*b*)	Rhymney Beds Silurian (*b*)
Zircon	x	x	x	x	x	x	x	x
Tourmaline	x	x	x	x	x	x	x	x
Garnet					x	x	x	
Rutile	x	x	x	x	x		x	x
Apatite	x	x	x	x	x	x	x	?
Muscovite	x	x	x	x	x	x		
Chlorite	x				x	x	x	
Anatase	x							
Barytes		x				x		
Serpentine				x				
Hornblende				x				

a, from Shannon. *b*, from Heard and Davies.

BIBLIOGRAPHY.

(1) Dixon, E. E. L. "Geology of the South Wales Coal-field (Pembroke and Tenby)," *Mem. Geol. Survey*, 1921, 31.
(2) Dorsey, G. E. "The Origin of the Colour of Red Beds," *Journal of Geology*, xxxiv, 1926, 31.
(3) Evans, J. W. "The Geological Structure of the Country around Combe Martin," *Proc. Geol. Ass.*, xxxiii, 1922, 208.
(4) —— *Handbook of the Geology of Great Britain*, "Devonian" generally.
(5) Heard, A., and Davies, R. "The Old Red Sandstone of the Cardiff Area," *Quart. Journ. Geol. Soc.*, lxxx, 1924, 489.
(6) Payne, J. H. *Proc. Somerset Arch. and Nat. Hist. Soc.*, v, 1854, 95.
(7) Raymond, P. E. *Amer. Journ. Sci.*, xiii, 1927, 36–7.
(8) Reynolds, S. H. "On a Silurian Inlier in the Eastern Mendips," *Quart. Journ. Geol. Soc.*, lxiii, 1907, 234.
(9) —— *Geology in the Field*, 317.
(10) Shannon, W. G. "Appendix on the Petrography of the Devonian Sedimentary Rocks," *Proc. Geol. Ass.*, xxxix, 1927, 137.
(11) Sollas, W. J. "On the Silurian District of Rhymney and Pen-y-Lan," *Quart. Journ. Geol. Soc.*, xxxv, 1879, 480.
(12) Strahan, A. "Geology of the South Wales Coal-field (West Gower)," *Mem. Geol. Survey*, 1907, 4.
(13) Ussher, W. A. E. "The Quantock Hills," *Mem. Geol. Survey*, 1908, 8–18.
(14) —— *Proc. Somerset. Arch. & Nat. Hist. Soc.*, lii, 1889.
(15) —— Geol. Mag., 1881, 444.
(16) —— *Proc. Somerset Arch. & Nat. Hist. Soc.*, lii, 1890.
(17) Mackie, W. *Trans. Edin. Geol. Soc.*, vii, 1896, 148.

The Petrology of the Culm Sandstones of North-West Devon and of the Dune Sands of Westward Ho!

By Brian Simpson, M.Sc., and Alan Stuart, M.Sc., F.G.S.
(University College, Swansea).

DURING the summer of 1933 one of us (B. S.) began work upon the age and correlation of the Culm Measures of North Devon, and the opportunity was taken to collect specimens of the sandstone and of the dune sands of Westward Ho! for a petrological examination. It was felt that a comparison of the mineral content of the Culm rocks with those of similar age in South Wales, upon which work was proceeding at University College, Swansea, might be interesting, and that an examination of the dunes of North Devon might reveal to what extent the Culm had contributed to their mineral composition, and also might confirm some of the conclusions regarding the origin of some of the minerals in the dunes of South Wales (1).[1]

The rock specimens were collected from the splendid coast exposures between Westward Ho! and Hartland Quay and from quarries in the neighbourhood of Bideford.

The cliff section reveals a series of sandstones and shales of varying thicknesses striking a little south of east, sharply folded, and pitching westwards. The sandstones here considered all appear to lie in the zones of *Anthracomya lenisulcata* and *Carbonicola ovalis* (2), that is, in the upper part of the Millstone Grit, and in the lower part of the Lower Coal Measures.

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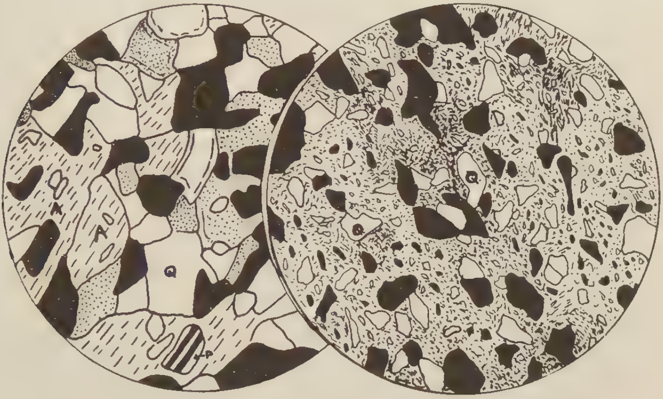
[1] Figures in parentheses refer to list of References at end of article.

In colour the sandstones vary between greys, yellows, and reds, the darker coloured rocks being the more compacted.

Some variation exists in grain size, which is generally very small, the coarsest specimens showing an average diameter for the minerals of 0·15 mm., whilst the finer-grained specimens present an average diameter of about 0·075 mm.: this variation is illustrated in Figs. 1*a* and 1*b*, which are camera lucida drawings of the rock slices between crossed nicols.



a *b*

FIG. 1*a*.—Fine grained blue-grey sandstone 60 yards north of Tut Hole, Abbotsham Cliff.

FIG. 1*b*.—Grey sandstone. Pit Quarry, Abbotsham Village. Q, quartz; P, plagioclase; A, amorphous groundmass. × 35.

A study of the rocks in section shows that the bulk of the material present is quartz which is variable from specimen to specimen, in both amount and form, the main shape being angular or subangular, but a subrounded form is not infrequent. Small quantities of fresh plagioclase, albite in tiny prismatic grains, magnetite, ilmenite and its decomposition product leucoxene, and sparsely distributed zircon occur. Varying amounts of sericite, siderite, and iron ores share the role of bonding material with secondary quartz. The secondary deposition of silica in optical continuity with the original grains has taken place to a marked extent, more especially in the relatively coarser-grained types. Evidence is seen at times, in structures such as that depicted in Fig. 2, that some amount of penecontemporaneous movement has taken place within these rocks similar to that shown by Davies, Dix, and Trueman (3) in the Coal Measure rocks of South Wales.

The Heavy Mineral Suite.

The heavy mineral suite does not display numerous species and the area investigated is not large enough, as yet, to indicate any variation of frequency in distribution. The mineral species, as revealed by crushing, bromoform, and magnetic separation, are listed below :—

- *Cubic.*
  - garnet.
  - sphalerite ?
- *Tetragonal.*
  - zircon.
  - rutile.
- *Hexagonal.*
  - tourmaline.
  - siderite.
  - corundum.
  - apatite.
- *Orthorhombic.*
  - brookite.
- *Monoclinic.*
  - chlorite.
  - sphene.
  - biotite.
  - muscovite.

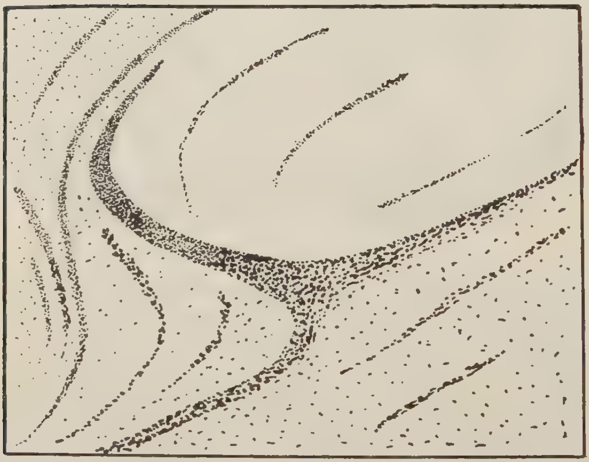


Fig. 2.—Diagram showing penecontemporaneous folding in purple sandstone half-mile east of Clovelly. × 5.

The grain size of the heavy minerals presents a remarkable uniformity in that most are of the order—length 0·15 mm., breadth 0·075 mm. Variations from this mode are noted below.

Garnet is very rare and displays no peculiar characters. It occurs in small anhedral grains with a purple coloration.

Sphalerite ? is extremely rare, occurring in grains determined by the well-marked dodecahedral cleavage, and is of a golden yellow colour (Fig. 3*l*.)

Zircon is the most common mineral in the suite. Several idiomorphic types are present, the commonest displaying the forms (100), (110), (111). Elongation parallel to the *c* crystallographic axis in types showing (100), (110), (311), produces a spindle-shaped crystal. Several stumpy forms are produced by the excessive development of the basal plane relative to the prism faces. Unequal development of the pyramidal faces gives the common form shown in Fig. 3*e*, whilst the combination of basal plane and prism, with a small development of the pyramid, gives a common type of square-ended prismatic crystal. Purple, yellow, and colourless varieties are present, the latter being mostly idiomorphic in the forms described above, and are often zoned, whilst those of the two former colours are invariably in rounded grains. A brown, faintly pleochroic type occurs but is not common. Inclusions are present in fair abundance, small zircons and rutiles being the most common, together with abundant dark opaque material. A frequent phenomenon in the clear zircons is the presence of a central dark or brownish core from which cracks radiate. Extensive cracking which has subsequently been infilled with dark opaque dust is common, as is also slight corrosion of the crystals (Fig. 3*d*–*h*).

Rutile is common in all samples, and varies in form from idiomorphic types showing (110), (101), to well-rounded grains. The grade size varies widely, but the average size is comparable with the other minerals. Geniculate twins on (101) are common, also less frequently a form twinned on (301) giving a sharp arrow-head twin. The colour varies from pale honey yellow to deep red brown. Most forms show good prismatic, and traces of the pyramidal, cleavages (Fig. 3*j* and *k*).

Tourmaline is ubiquitous, usually displaying a partially rounded prismatic form having an average size of 0·12 mm. × 0·09 mm. In addition to a colourless variety, pale yellow, brown, deep brown, and blue types occur (Fig. 3*q*).

Siderite is common in grains the irregular shape of which is determined by the rhombic cleavage. It is seldom colourless, usually being a brownish cream. The grains (which occur in the heavy crop) give a decentralized uniaxial negative figure, and show symmetrical extinction (Fig. 3*m*).

Corundum occurs in blue angular grains and is very rare.

Apatite is common in idiomorphic crystals showing the prism and basal plane. Anhedral and rounded grains are not infrequent. The crystals are usually larger than the average size of the other "heavies", being about 0·225 mm. × 0·12 mm. Most crystals are water clear, whilst others show a grey colour. Irregular inclusions are rare and sporadic in their distribution within the crystal, but some show a central dark portion. A basal parting is frequently displayed in the idiomorphic forms.

Brookite is of frequent occurence, and is undoubtedly authigenic. It occurs in idiomorphic grains displaying the forms (122), (110),

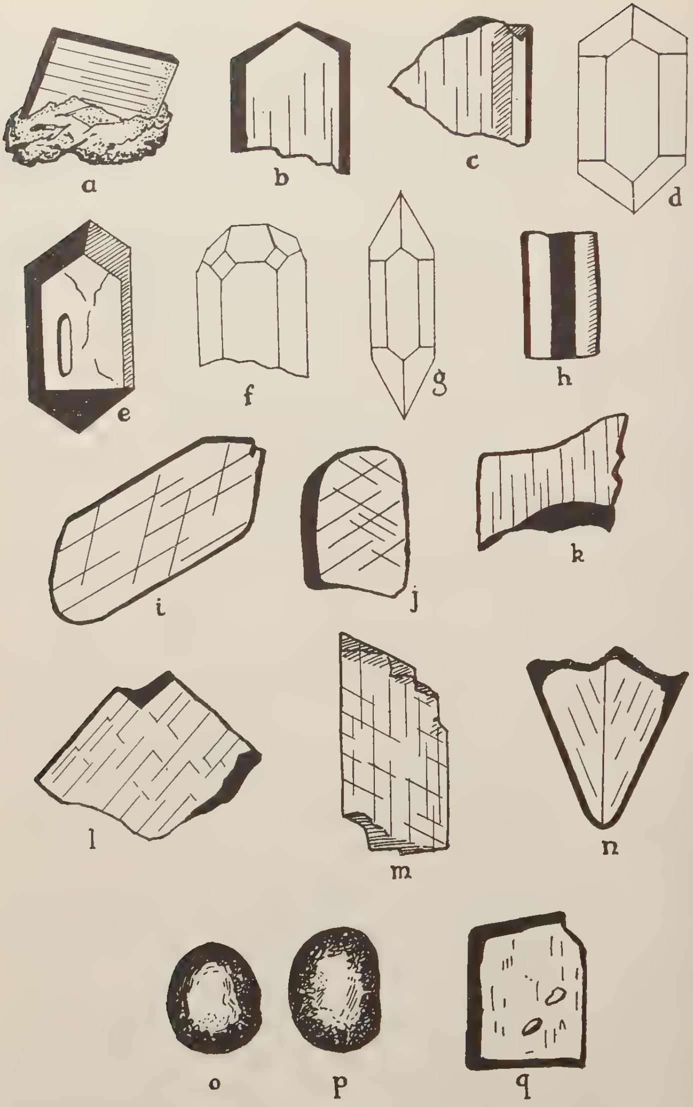


FIG. 3.—Minerals from the Culm Sandstones.

(*a*) Brookite developing on sphene.
b, *c*, Brookite.
d–h, Zircon.
i, Sphene.
j, *k*, Rutile.
l, Sphalerite (?).
m, Siderite.
n, Rutile twinned on (301).
o, *p*, Rounded purple zircons.
q, Tourmaline.

All figures × 100.

also in tabular crystals parallel to (100). The colour is usually a pale honey yellow, although a deeper coloration is present in some grains. Striations are present parallel to the vertical axis. In convergent light the mineral displays the usual strong crossed axial dispersion, with resultant anomalous polarization colours and absence of total extinction. In a few cases tabular crystals have been observed developing on crystals of sphene (Fig. 3*a*, *b*, *c*).

Chlorite occurs in all specimens as broad basal flakes, being mostly green in colour and faintly pleochroic ; a large number, however, are colourless. Some of the green species are isotropic.

Sphene is very rare. It occurs in grains determined by the (110) cleavage and at times shows traces of that parallel to (111). The crystals are usually clouded and are cream yellow in colour. In many cases partial alteration to brookite is seen (Fig. 3*i*).

Biotite and *muscovite* occur in the usual ragged forms and call for no special mention here, except that the former is rare and fresh and the latter is common. Some of the muscovite plates are crowded with inclusions of colourless single crystals and geniculate twins of rutile.

Iron ores are ubiquitous and common and are represented by the following :—*magnetite, ilmenite* and its decomposition product *leucoxene, haematite*, and *pyrrhotite*. No idiomorphs of magnetite or ilmenite have been seen.

A few specimens gave the general appearance of *andalusite*, for which a keen search was being made, but a closer examination revealed the minerals to be clouded apatites with anomalous biaxial or uniaxial optic normal figures.

THE MINERAL SOURCES.

The restricted composition of the detrital mineral suite, together with the abundance of very small and well-worn grains, especially of purple and yellow zircon, red rutile, and brown and blue tourmaline, indicates that the source of the material lay largely in an older sedimentary series. Especially distinctive are the deep purple zircons which in many cases are almost spherical amd must have suffered prolonged attrition (see discussion in (6)). The close resemblance which the mineral suite bears to that of the Lower Coal Series (4) and the Millstone Grit (5) of South Wales—rocks which are in part the zonal equivalents of these—is remarkable.

The only detrital mineral which appears in truly sharp idiomorphic form is colourless zircon, often zoned, and this together with the small amount of fresh biotite may have been derived from an acid igneous source not far distant. The remaining detrital minerals call for no special mention other than the descriptions already given.

Of the authigenic constituents, brookite is the most interesting, and it has been observed growing on crystals of sphene in a few instances. No actual examples of its derivation from rutile have been observed, but it most probably derives its origin from the alteration of that mineral along with the sphene. No anatase has been seen.

The Dune Sands.

The dunes of Westward Ho! from which specimens were taken extend northwards along the coast for a distance of two or three miles until breached by the combined estuary of the Rivers Torridge and Taw. The sands were well sampled at intervals and subsequently separated in bromoform and by magnetic means. The following minerals were found:—

- *Cubic.*
  - magnetite.
  - fluorite.
  - various garnets.
  - pyrite.
- *Tetragonal.*
  - cassiterite.
  - anatase.
  - rutile.
  - zircon.
- *Hexagonal.*
  - apatite.
  - calcite (+ a manganiferous var. ?)
  - dolomite.
  - siderite.
  - tourmaline.
  - haematite.
  - ilmenite.
  - quartz.
- *Orthorhombic.*
  - andalusite.
  - enstatite.
  - hypersthene.
  - staurolite.
  - topaz.
  - zoisite.
- *Monoclinic.*
  - orthoclase.
  - biotite.
  - muscovite.
  - chlorite.
  - sphene.
  - hornblende.
  - tremolite.
  - actinolite.
  - diopside.
  - hedenbergite.
  - augite.
  - aegirine-augite ?
  - clinoenstatite (?).
  - epidote.
- *Triclinic.*
  - kyanite.
  - albite.

In addition to these, leucoxene, serpentine aggregates, fragments of shelly material, chert, sponge spicules, and a foraminifer—*Operculina*—are present. One pale subrounded yellow green grain, with medium refractive index and low double refraction, has been referred to glauconite.

Notes on the Minerals from the Dune Sands.

Magnetite. Rare. In small angular grains and as inclusions in grains of green serpentine in sufficient quantity to bring the latter down in the highly magnetic crops.

Fluorite. Rare. In colourless angular fragments with fluid inclusions.

Garnet. Very abundant. Usually small, about 0·2 mm. diameter, in rounded and subangular grains; colourless, pink, green, and pale yellow. The coloured varieties often show strongly etched surfaces and optical anomalies. Minute dodecahedra of pale yellow and pink garnets are occasionally seen. One piece, brownish orange in colour, has been referred to *spessartite*? and a dark green zoned variety to uvarovite or andradite. The pink variety is dominant, and the colourless types most rare (Fig. 4*g* and *h*).

Pyrite. Not common. No noteworthy characters.

Cassiterite. Scarce. Rounded golden yellow and pale yellow grains, high refractive index, and double refraction; showing good pyramidal and prismatic cleavages.

Anatase. Scarce. Brownish yellow rounded basal plates showing perfect (001) and traces of (111) cleavages. Negative. Very low double refraction.

Rutile. Common. Small foxy red, yellow and brown subangular, and well-rounded grains; fractured prisms having average diameter of 0·15 mm.

Zircon. Common in small rounded grains and worn prisms occasionally zoned (about 0·15 mm. diameter or length). Usually colourless. A few pale yellow and purple grains occur. Rare in larger clear colourless and pink flattened prisms up to 0·35 mm. long. Inclusions typical, i.e. rod like and fluid.

Apatite. Fairly common, usually small, > or < 0·15 mm. Colourless, rounded; a few with opaque centres, and others with small black inclusions; $(10\bar{1}0)$ cleavage sometimes distinct.

A colourless well-rounded grain, 0·15 mm. in diameter (Fig. 4*i*), distinctly pleochroic in polarized light from colourless (slow) to pale mauve (fast), having low double refraction, and a medium high refractive index, was finally discovered to be apatite, although it was at first thought it might (amongst other possibilities) be a specimen of dumortierite of the type described from the Land's End Granite (12). Traces of a cleavage parallel to a prism are seen. In convergent light, however, with careful manipulation a faint very inclined negative uniaxial figure was observed, so definitely restricting the various possibilities. This species of apatite (possibly a manganiferous variety) must be added to the growing list of purple minerals which might be confused in permanent mounts.

Carbonates. Abundant in irregular fragments and worn rhombs. Colourless varieties include calcite, dolomite, and siderite which is usually brownish or cream. A purple, markedly pleochroic variety, very rare, has been referred to manganiferous calcite. It has the calcite refractive indices and is uniaxial negative. Composite grains of calcite, possibly marble, sometimes have the constituent crystals arranged roughly optically parallel so that good directions images may be seen, and these sometimes open on rotation giving a pseudo-biaxial negative figure of small optic axial angle.

Tourmaline. Abundant, displaying the usual characters in brown, blue, pink, green, purple, yellow, party-coloured, and colourless varieties. Schorl frequent. A striking variety with intense pleochroism, E, pale mauve ; O, dark Prussian blue, and colour sometimes irregularly distributed, was remarkable for good development of a prismatic cleavage and a strong basal parting. These characters made it difficult to differentiate from a possible orthorhombic mineral giving an optic normal figure.

Haematite. Fairly common. In scales and irregular fragments.

Ilmenite. Scarce. Fresh grains very scarce. Irregular rounded grains.

Quartz. Bulk. No special features. Subangular and rounded grains often almost opaque with minute black indeterminate inclusions. Other inclusions include rutile needles, apatite, tourmaline, epidote, and chlorite.

Andalusite. Fairly common. Colourless angular fragments with the characteristic black inclusions at random. Pink pleochroic grains much less common.

Orthorhombic Pyroxenes. Enstatite. Scarce. Colourless cleavage fragments and prisms, the latter showing straight extinction, high refractive index, and low double refraction. Slow length. *Hypersthene.* Scarce. Pale green worn prisms giving characteristic pleochroism, straight extinction, low double refraction, slow length.

Staurolite. Fairly common. Pale yellow pleochroic irregular grains and fractured idiomorphs, commonly with black inclusions.

Topaz. Fairly common. Mainly rounded and subangular basal plates, with characteristic fluid inclusions and showing emergence of positive bisectrix (Fig. 4*c*).

Zoisite. Not scarce. Colourless, prismatic, with perfect cleavage (010), high refractive index, low double refraction, 2V large, straight extinction (Fig. 4*b*).

Certain colourless crystals (Fig. 4*d*), sometimes faintly tinged with yellowish green, non-pleochroic, having a high refractive index and low double refraction (less than quartz), multiply twinned between crossed nicols (Fig. 4*f*), straight extinction upon parts into which twinning does not extend, have been referred to zoisite. The plates which are parallel to a perfect cleavage show twinning upon a plane not at right angles to the cleavage. The diagnosis agrees with plates of zoisite elongated parallel to the trace of the twinning planes, giving slow length (Z), the composition plane being (031).

Orthoclase. Common. Cleavage fragments, some very rounded and altered.

Biotite. Scarce. Fresh, irregular, and rectangular, brown cleavage plates with characteristic optic figure.

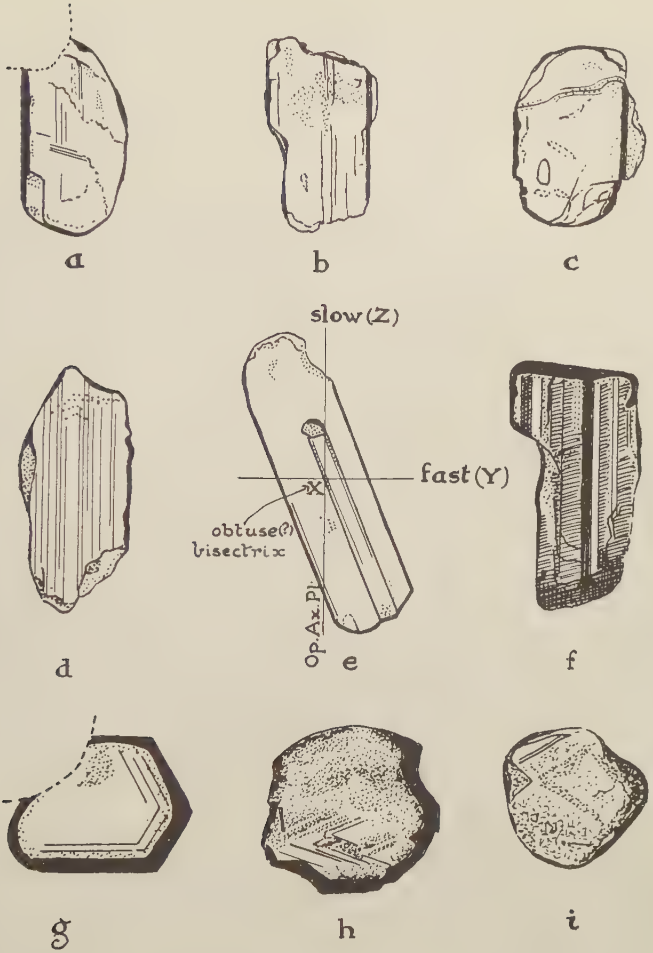


Fig. 4.—Minerals from the Dune Sands of Westward Ho ! :—

a, Glaucophane : lower part mauve, pale green in upper third.
b, Zoisite : colourless, striated. Between crossed nicols shows twinning.
c, Topaz : basal cleavage fragment.
d, Zoisite : pale green almost colourless, striated, shows twinning between crossed nicols.
e, Pyroxene (Clinoenstatite ?) : Colourless. Shown in extinction position.
f, Zoisite : Illustrating appearance of twinned crystal between crossed nicols.
g, Garnet : Dark olive green, zoned.
h, Garnet : Pale pink, strongly etched.
i, Apatite : almost colourless in ordinary light, distinctly pleochroic, O colourless, E pale mauve. All figures × 100.

Muscovite. Very rare. Cream coloured flakes with 2E about 45° and a value for β higher than in common varieties.

Chlorites. Very common. In various shades of green and yellow. In plates, fibrous or spherulitic aggregates. Certain flakes in various shades of green are isotropic or nearly so, some green cleavage flakes with very low double refraction and large 2V, negative, are faintly pleochroic.

Sphene. Rare. A few small irregular pale yellow and partly altered grains with very high refractive index and double refraction exhibiting traces of (110) cleavages are referred to this species.

Amphiboles. Very common. Common *hornblende* occurs mainly in worn prisms, intensely pleochroic; extinctions up to 20°. Members of the *actinolite-tremolite* group occur commonly in pale green to colourless frayed prisms and cleavage fragments, in which faint pleochroism, in coloured varieties, is seen from pale yellow to green, 2V large, negative. Extinction $\gamma \wedge c$ up to 17°.

Glaucophane is rare. Occurs in ovoid grains about 0·25 mm. long. Pleochroism distinct, Z dark lavender to pale lavender. Occasionally altered to a green decomposition product (Fig. 4*a*).

Monoclinic Pyroxenes. Diopside, *augite*, and *diallage* occur in worn prisms and cleavage grains, the two former being very common, the latter rarer. The first is pale green or colourless, optically positive, 2V about 60°, extinction $\gamma \wedge c$ up to 32°. Augite occurs in pale brown or yellowish brown crystals with high extinction angles, positive character, 2V about 70°. Opaque inclusions regularly arranged, common. A dark green variety with extinction angles up to about 45°, low double refraction and distinct extinction dispersion has been referred to *hedenbergite*. A yellowish green monoclinic idiomorphic plate showing traces of zoned growth evidently lying on the (100) face, and showing in convergent light a central optic axial figure, $2V > 80° < 90°$, negative, has been referred to *aegirine-augite*.

A colourless non-pleochroic mineral (Fig. 4*e*), monoclinic ?, apparently twinned on (100), with medium high refractive index, low double refraction, giving an extinction angle of $Z \wedge c = 20°$, lying so as to show the emergence of an obtuse (?) bisectrix (X) nearly parallel to the microscope axis (thus making the optic axial plane perpendicular to (010) has been ascribed to a member of the clino-enstatite group of pyroxenes—more material is necessary for study, however, and search is to be made for this in other sands.

Epidote. Abundant. In green, pale yellow, and colourless worn grains and cleavage plates displaying the usual properties. Pleochroic in coloured varieties; 2V near 90°; negative.

Kyanite. Scarce. In the usual worn tabular crystals with perfect cleavage and partings, low double refraction, high refractive index, 2V large, negative, extinction angle 30° on (100).

Albite. Scarce. Small colourless cleavage fragments showing twinning or not, according to whether lying on (001) or (010). Refractive indices less than Canada balsam, large 2V.

SOURCES OF THE MINERALS OF THE DUNE SANDS.

Theoretical considerations would suggest that the origin of the minerals of the sands must lie mainly in the rocks being denuded at the present time along the coast, which is remarkable in that very few streams of any size flow to it. The main drainage system of Devon and Cornwall trends south-eastwards to the English Channel. In addition, complications do not arise owing to the presence of glacial deposits, therefore the sources of the various members of the suite must be derived in the main from the rocks of the Culm, the metamorphosed sediments of Devonian age, and the igneous rocks abutting on the coast further south. In addition, some material may have been derived from the sediments being denuded by the Rivers Torridge and Taw, but these again are almost wholly of Culm and of Devonian age together with a very small portion of Trias. The granites of Land's End, Bodmin Moor, and St. Austell have no doubt also contributed to the sands.

The contribution which the Culm rocks have made is easily recognized. The small rounded crystals of zircon and apatite are very characteristic, larger zircons from other sources are unexpectedly rare. The greater part of the remaining minerals with the exception of possibly glaucophane can be confidently ascribed to the sedimentary rocks and igneous complexes further to the south, namely the Bodmin, St. Austell, and Land's End Granites and their metamorphic aureoles. For example, the pale yellow optically anomalous garnets as well as pale diopside can be matched in the calc flintas from the Tremore and Tregullan districts ; the peculiar deep brown and blue tourmaline with rough cross fracture and vertical cleavage may be from the St. Agnes Head Granite, whilst the andalusite, actinolite, epidote, and pink and colourless garnets showing optical anomalies can be matched in the igneous complexes connected with the various granite masses, as can also the topaz and cassiterite (7, 8, 9). The source of the kyanite and staurolite is most probably to be found in the Pliocene outliers of West Cornwall (10), the material being carried northwards along the coast. As for the glaucophane the nearest record for this mineral is the dune sands at Newgale (11), South Wales. The occurrence of pyrrhotite in fair quantity in the Culm, led to the expectation of finding it in the sands. None has, however, been seen as yet. In this connection it is significant that in the study of the Dune Sands of South Wales pyrrhotite was only found, in small quantity, near the mouths of the Rivers Tawe and Neath, which are the largest streams which carry detrital minerals from the Coal Measures in which pyrrhotite occurs abundantly. It is evident that this mineral cannot survive as a true detrital for any appreciable time. With the exception of a very few of the rarer species the mineral composition (*per se*) of the Westward Ho ! sands is almost identical with those of South Wales, and this lends support to the conclusions drawn in 1924 (op. cit., 2), that many of the non-local minerals of the latter had their source in Devon and Cornwall, and were collected under the influence of the South West winds. Differences in frequencies in the South Wales sands might be accounted for by the extra supply of certain species from the glacial deposits of Wales, upon which work is now proceeding.

One of us (B. S.) wishes to record his thanks to the Government Grants Committee of the Royal Society for financial assistance in the investigation of the Culm rocks.

REFERENCES.

(1) Stuart, A. "The Petrology of the Dune Sands of South Wales": *Proc. Geol. Ass.*, xxxv, 1924, 316.

(2) Simpson, B. "On the Presence of the Zones of *Anthracomya lenisulcata* and *Carbonicola ovalis* in the Culm Measures of North Devon": Geol. Mag., lxx, 1933, 433.

(3) Davies, D. F., Dix, E., Trueman, A. E. "The Boreholes of the Cwmgorse Valley": *Proc. South Wales Inst. of Engineers*, xliv, 1928, 38, fig. 19.

(4) Stuart, A. Appendix to (3).

(5) Work proceeding by A. Stuart and F. Pascoe. Personal Communication.

(6) Boswell, P. G. H. "On the Distribution of Purple Zircon in British Sedimentary Rocks": *Min. Mag.*, xxi, 1928, 310.

(7) Reid, C., Flett, J. S., and Others. "The Geology of the Land's End District": *Mem. Geol. Survey*, 1907.

(8) Ussher, W. A. E., and Others. "The Geology of the Country around Bodmin and St. Austell": *Mem. Geol. Survey*, 1909.

(9) Reid, C., and Scrivenor, J. B. "The Geology of the Country around Newquay": *Mem. Geol. Survey*, 1906.

(10) Milner, H. B. "The Nature and Origin of the Pliocene Deposits of the County of Cornwall, and their bearing on the Pliocene Geography of the South-West of England": *Quart. Journ. Geol. Soc.*, lxxviii, 1922, 348.

(11) Thomas, H. H. "The Country around Milford": *Mem. Geol. Survey*, 1916.

(12) Groves, A. W. "The Identification of Dumortierite as Grains, Dumortierite in Cornish Granites": *Min. Mag.*, xxi, 1928, 489.

The Calcareous Tufa Deposits of Buxton, near Taungs, Cape Province.

By M. P. Latter, B.A., D.I.C., A.I.M.M.

A FEW miles to the west of, and running approximately parallel to, the main Rhodesian Railway from Kimberley and the Cape, there is a well defined line of hills, which is the eastern edge, and forms the scarp face of, the Kaap Plateau. Between this plateau and the railway is a belt of flat low-lying ground through which the Great Harts River runs southwards to the Vaal. In the vicinity of Taungs Station, between Warrenton and Vryburg, the scarp line is running nearly due north and south, and is only four to five miles distant from the railway ; followed southwards it gets farther away from the railway and assumes a more south-westerly course. The Kaap Plateau is formed of dolomite of the Campbell Rand

Series of the Transvaal System, corresponding to the dolomite in the Transvaal. The formation dips gently to the west at angles of 2–3°. Along the escarpment the dolomite rests conformably on dolomite shales, the latter frequently forming a series of terraces from the base of the plateau upwards. Lying unconformably against the dolomite to the east are the Lower Karroo Beds, which are largely concealed by secondary limestone and the recent alluvium of the Harts River basin.

At a number of points along the escarpment small valleys have been formed by streams issuing from the dolomite country to the west, and in many of these—besides at certain points where lime-bearing water has flooded over the edge of the escarpment—calcareous tufa has been deposited. By far the most important of these limestone deposits is that at Buxton, situated eleven miles by road south-west from Taungs Station. This occurrence has been worked by the Northern Lime Company, Ltd., since 1916, production first actually starting under Nolan in 1915. Since then production of, and demand for, the lime from here has been steadily increasing. The annual tonnage of rock broken now exceeds 300,000, the figure previously being around 200,000. It is estimated that there is still three to four million tons available.

GENERAL DESCRIPTION OF THE OCCURRENCE.

Referring to the text-figure accompanying this paper, it will be seen that there are three separate main deposits of a payable nature—two at the bottom, on either side of the dry valley, and one in the valley itself at its head. These deposits were not originally separated, but are residual blocks of one very much larger deposit, which probably filled the whole of the present dry valley shown on the plan, and which has since been in greater part eroded.

The slight elevation of the deposits above the plain of the Harts River valley is a very great advantage in the quarrying of the limestone, as none of the limestone—payable or waste—has to be hauled.

Only the deposit on the south side, at the bottom of the valley (" A " Block on the plan), has so far been opened up on any scale. Owing, however, to the erosion of the calcareous tufa in the valley over the greater part of its length, one can calculate with some precision the limestone tonnages in all three deposits ; for, what one really has here is one triangular deposit with the whole of the middle missing, the only conjectural factor being the depth of the limestone on and near the periphery.

The considerable quarrying that had taken place in " A " Block, has brought out one rather salient fact, namely that the old valley sides, where they have been exposed from under the secondary deposits, frequently present a " stepped " appearance, the deepest deposit being almost invariably towards the middle of the valley,

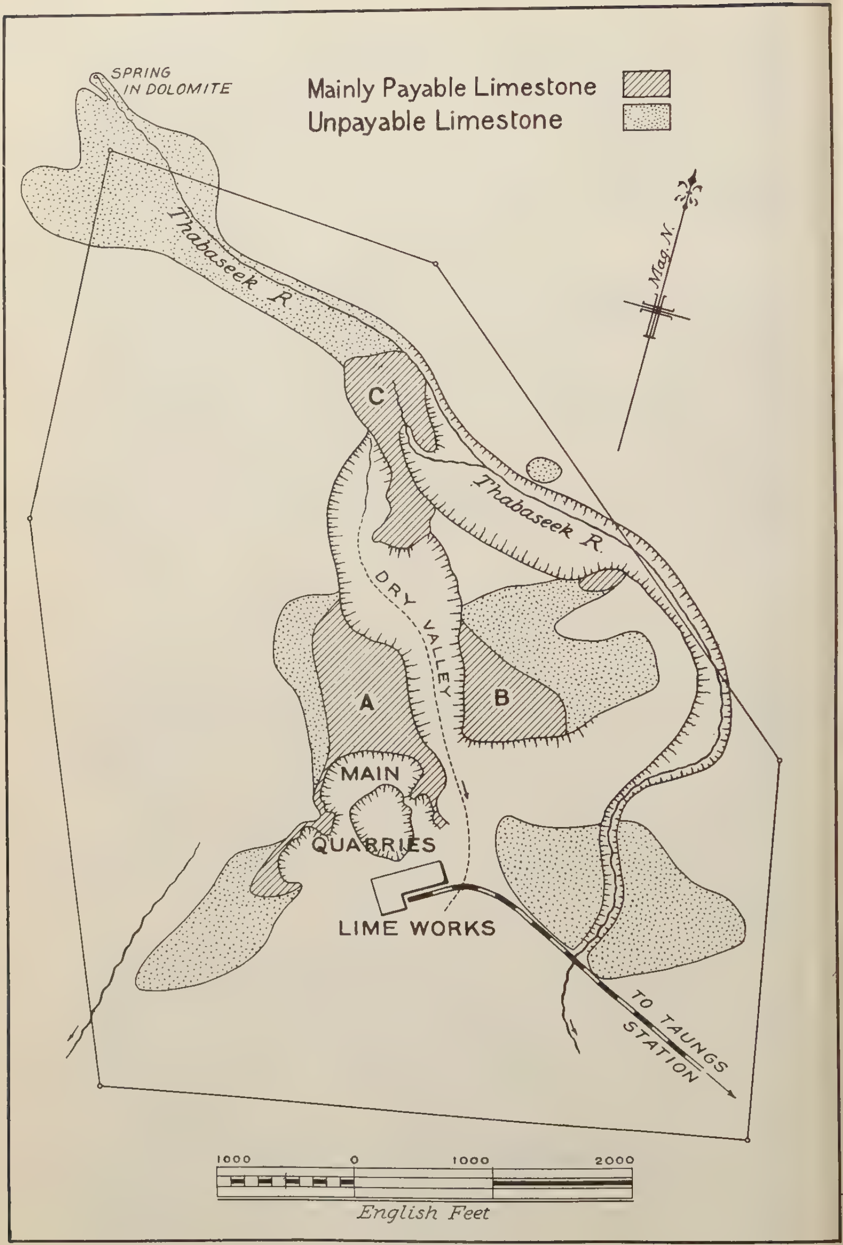


Fig. 1.—Sketch Plan of the Buxton Lime Deposits, near Taungs, Cape Province.

except perhaps in the case of certain solution pockets that may have existed in the dolomite country rock. As the thicknesses thus tend to decline in steps as one passes from the outer boundary walls of the deposit to the inner, where they overlook the valley, the quantity of limestone is rather more than it would be were the deposit wedged off along an evenly inclined plane.

In defining the outer boundary line between the payable and unpayable limestone, the point is taken where the lumpy, hummocky limestone (i.e. the good) gives place to flat, smooth-looking limestone, this latter generally indicating a high admixture of silica. In this outer rim of unpayable limestone there are generally areas of limestone breccia, consisting of numerous pieces of dolomite and shale embedded in a cement of secondary limestone, similar to the breccias seen in the quarries near the floor of the deposit, described below. Beyond the unpayable limestone, which seldom forms a wide band and is merely a thin surface capping to the underlying dolomite, the dolomite country rock begins to appear.

CHARACTER OF THE LIMESTONE.

The limestone is of very great purity as compared with the average limestone deposits in South Africa, averaging 97–98 per cent $CaCO_3$: it is much less variable, too, in quality. The best quality is a cream-white, or buff-white, porous, crystalline limestone. Stratification in the deposit is very indistinct, as would be expected in a deposit of this nature.

Scattered through the payable limestone in irregular patches and lines there is about 10–15 per cent of waste or bastard limestone. This is locally termed " Bushman " and is quite valueless. It is reddish and highly siliceous, containing fragments of dolomitic shale and dolomite. Dirt pipes leading down into dirt caves occur also through the deposit, and such caves may be immediately adjacent to very good quality limestone. In some parts of the quarries there is so much sand and dirt intermixed with the calcareous tufa that none of it can be mined, and islands or headlands of this nature have had to be left standing.

The deposit either rests directly on dolomitic shale, or there is, between the two, an irregular layer or band of breccia. This breccia, which might in places better be termed conglomerate, consists of big fragments of " blocky " and sub-angular shale together with numerous small, rounded, and sub-angular shaly pebbles set in a matrix of secondary siliceous limestone. In the footwall shale crystalline calcite may occur in narrow bedded veins or as infillings along nearly vertical joints.

AGE AND HISTORY OF THE DEPOSIT.

As Wybergh points out (1),[1] this deposit cannot be included under those classed as of " recent " age, as the Taungs skull, *Papio Antiquus* sp. nov., discovered by S. H. Haughton (2) in 1920, dates the deposit to comparatively ancient times, namely early or pre-Pleistocene age.

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[1] The numbers in parentheses refer to References at end of article.

The sequence of events that has brought about the present disposition of the limestone deposits appears to be as follows :—

(1) Carving out of the present dry valley by river erosion. This valley represents the original course of the river.

(2) By selective solution of the lime from the dolomite and subsequent surface evaporation of the water, deposition of calcareous tufa to the present level of the scarps on either side of the valley—or possibly higher.

(3) Diversion of some of the water by way of a new valley to the east—the present channel of the Thabaseek—as the other valley became heaped up with tufa.

(4) Simultaneous cutting down and deepening of the two valleys, and progressive formation upstream of (the present-day) ravines. The vertical sides and cañon-like character of these valleys indicate somewhat arid conditions even at that time, as also a distant source for the river (cf. the Grand Cañon of Colorado, and the cañon formation below the Victoria Falls).

(5) Finally, the complete diversion, or capture, of the Thabaseek by the newer channel, through the more rapid cutting back of its gorge, and the relegation of the older valley to a dry state, after the re-excavation of the latter had been carried to a very considerable extent.

(6) Further slight and irregular erosion in the older valley by small streams formed during the rains. The insignificant channels in existence here to-day represent the final stage of this erosion, and are slowly removing the deposit at the head of the valley. (N.B. The tufa deposits in this valley could never have been altogether denuded by such diminutive channels working backwards, as, with the main waters of the Thabaseek diverted into the newer valley, the catchment area for such small streams would have been negligible.)

(7) Present-day deposition of lime above the head of the gorge of the newer Thabaseek valley. The Thabaseek flows as far as this gorge on a gentle incline from its source on the dolomite plateau more than twenty miles distant to the west.

Owing to the greatly diminished rainfall in the district, practically stationary conditions now exist in the older, dry valley.

SELECTIVE SOLUTION OF THE LIME FROM THE DOLOMITE, AND FORMATION OF THE CALCAREOUS TUFA.

When one considers the high percentage of magnesia in the dolomites of the Kaap Plateau—up to as much as 20 per cent MgO it is remarkable that such an exceedingly pure, and at the same time extensive, deposit of calcium carbonate exists. There is, however, very little soil on the plateau, and the dolomite in most places appears at the surface, practically the only vegetation being a semi-desert shrub commonly termed the vaalbosch. Also, unlike the Dolomite Series of the same age in the Transvaal, there is practically no chert. The lime, on account of its greater solubility, is more readily dissolved from the dolomite than the magnesium carbonate, so that the water issuing off this dolomite plateau becomes saturated with lime, and by subsequent surface evaporation during its passage down to the plains gives rise to these deposits of nearly pure calcium carbonate.

Other very pure secondary limestone deposits on the other hand, such as those formed in vleis or swampy ground, have been undoubtedly formed by precipitation through organic agency, the abundant bits of vegetable matter in such deposits affording clear evidence of their origin.

In conclusion, the author would like to record his thanks to the Northern Lime Company, Ltd., and The Central Mining and Investment Corporation, Ltd., for their willingness in permitting this paper to be published. To Mr. V. C. H. R. Brereton he is indebted for much assistance in the field, and particularly would he like to acknowledge his thanks to Mr. D. R. Robinson, draughtsman to the above Corporation, for his help in preparing the text-figure in this paper.

REFERENCES.

(1) W. Wybergh. *The Limestone Resources of the Union*, ii, 116–19. *Geological Survey Memoir No. 11*, 1920 (Pretoria).

(2) S. H. Haughton. " A Species of Baboon in Limestone Deposits near Taungs," *Transactions of the Royal Society of South Africa*, xii, 1924–5, lxviii (Capetown).

The Cambrian Genus *Stenotheca*.

By Edgar Sterling Cobbold, D.Sc., F.G.S.

(PLATE XXIII.)

Introduction, mainly historical.

In labelling specimens about 1866 from the Menevian of St. David's, South Wales, Salter used this generic term for *Stenotheca cornucopia*, which is the genotype.

Hicks (1872, p. 180)[1] shortly described the species and figured two of the shells. The specimen represented by his fig. 12 is the holotype and is preserved in the Sedgwick Museum at Cambridge. Through the courtesy of the curator, the writer has had the opportunity of studying the holotype and two other specimens from the collection, labelled apparently by Salter and which, presumably, Hicks had before him. All three seem to have been prepared since his figures were drawn and now present more details than he had opportunity to observe. The second figured specimen has not been identified.

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[1] Figures in parentheses refer to list of References at end of Article.

Matthew (1885) described five species, all compressed in shale, under *Stenotheca* Salter and regarded them as "Gasteropoda or Heteropoda".

Walcott (1886, p. 128) referred the gastropod species *Metoptoma ? rugosa* Hall to Salter's genus and, with that species in mind, because no generic diagnosis had been given, proposed the following :—

"Shell depressed conical ; aperture oval, elliptical or elongate oval, apex excentric and curved over towards one end of the shell ; surface marked by more or less strong undulations and lines of growth."

Walcott (1890, p. 617) refers Hall's species to "*Stenotheca* (?)".

Matthew (1890), after an intensive study based on new material of his species of the genus, gives in full detail his reading of the characters of the shells and proves their crustacean affinities, assigning them to the "Phyllopoda".

Grabau (1900, p. 601) referred Hall's species, *Metoptoma* (?) *rugosa*, together with others, to Salter's genus but expressed grave doubts as to their being congeneric.

Grabau and Shimer (1909) erected the genus *Helcionella* to receive Hall's *Metoptoma* (?) *rugosa* and other congeneric species. The same authors (1910, p. 373) place the genus *Stenotheca* under the "Phyllopoda".

It seems clear that when Walcott wrote the above quoted generic diagnosis, he had prominently in mind those species which have, since that time, been removed to *Helcionella* and retained among the Gastropoda ; this to a certain extent vitiates that diagnosis, but before any fresh attempt can be made, a detailed description of all available material should be made of the genotype *S. cornucopia*, the holotype of which is the most important.

STENOTHECA CORNUCOPIA Salter M.S. (Pl. XXIII, Figs. 1*a* and *b*.)

1872. *Stenotheca cornucopia* Salter M.S. ; Hicks, p. 180, pl. viii, figs. 12 and 13.

Holotype.—No. 14, A 844, in the Sedgwick Museum collection, Cambridge. The left side of an almost complete univalve carapace, showing in considerable measure its original convexity.

Description.—A pyramidal univalve with apex reflexed towards the anterior end of the shell. Aperture : elongate, possibly egg-shaped, decidedly widest in front, flattened or contracted in the middle, swelling out again towards the dorsal region, gently curved in the side view. Outline : anterior slope, almost straight from the notch under the apex to the antero-ventral angle ; ventral curve, gently convex downwards, to a certain extent damaged in the holotype especially along its anterior half ; postero-dorsal curve, continuous with increasing rate of curvature towards the slightly recurved apex, undulating at the crossing of each rib (see below). Apex remarkably well preserved in the holotype; as seen under a high power it is a uniformly rounded body, not truly spherical but bounded by a segment of an ellipse on the free margin and by a segment of a circle on the side adjoining the rest of the shell; its vertical diameter is 0·20 mm. and its horizontal length is 0·125 mm., its area being about one hundredth part of that of the whole shell. This body is without features except form. In the next adjoining space, about 0·37mm. wide, there are about twenty raised, concentric striae covering three incipient undulations or ribs and the hollows between them. On the body of the shell similar raised striae may be detected near the anterior margin where the ribs are narrowing and less in evidence; where these are more fully developed the striae tend to disappear, and the surface is closely granular or covered with minute tubercles with no obvious arrangement such as is noticed below (see p. 466).

The two areas above mentioned are evidently the "cephalic and thoracic regions" of Matthew (op. cit., p. 133, to which he also calls attention in the explanation of his plate ix, fig. 3). The remainder of the shell surface may be divided longitudinally into three regions, (1) the dorsal convexity, (2) the median sinus, (3) the anterior convexity. The whole side of the shell is traversed by a uniform series of concentric undulations or ribs, of which twelve may be counted in the dorsal region, in addition to the three incipient ones already mentioned. These ribs are widest at the dorsal margin and attenuate as they pass across the dorsal convexity, almost every other one dying out on attaining the median sinus, the remainder passing on to the anterior region. Whether they actually cross the margin on this anterior side or are interrupted is at present uncertain; that they continue across the dorsal margin without deviation or interruption of any kind is quite clear. Test: probably extremely thin, represented now by a grey film seen between the ribs, but not on their summits, which have a fine granulation somewhat similar to that of the surrounding rock.

Dimensions of holotype in mm.—Length at aperture, 1·50; height, 1·10.

Locality.—Porth-y-rhaw, St. David's, South Wales.

Horizon.—Middle Cambrian, Menevian.

This description is written on the hypothesis that the shell is bilaterally symmetrical.

REMARKS.

The systematic position of the genus has always been dubious. At first Hicks suggested that it was a Pteropod. Matthew in his earlier work (1885) placed it under the Gastropoda but later (1890) assigned it to the Phyllopoda. Walcott (1886), probably influenced by having species now assigned to *Helcionella* in his mind, reverted to Gastropoda. Grabau (1900) retained it under the same Order though he evidently had some doubt. Ten years later Grabau and Shimer definitely placed it under the Phyllopoda, which has more recently been abandoned as an Order, the species being ranged under Anostraca, Notostraca, and Conchostraca (see Eastman's *Zittel.* 1913, p. 732).

At present the writer thinks *Stenotheca* may be placed provisionally under the Notostraca.

OTHER SPECIMENS FROM PORTH-Y-RHAW. (Pl. XXIII, Figs. 2 and 3.)

The two other specimens in the Sedgwick Museum are too much damaged by crushing to be specifically determined.

No. 15, A 279 (Pl. XXIII, Fig. 2) is the external impression, or the interior of a right side. In this the apex is situated relatively further back than it is in the holotype of *S. cornucopia*, the anterior margin is concave instead of nearly straight, the dorsal margin is less convex, and the side ribs are accentuated and crowded together ; all may well be attributed to deformation in the rock, perhaps before consolidation ; the apex, it will be noted, is pointed ; possibly this is an original feature.

Dimensions.—Apertural length, 3·25 mm. Height, 1·75 mm.

No. 15, A 912 (Fig. 3) is a composite of ; in the upper third, the interior or external impression of the left side, with obscure traces of about ten ribs and a secondary fold possibly along the course of a median sinus ; in the median fifth, the irregular surface of the filling of the carapace ; and in the remainder, the damaged exterior of the right side, with portions of the test and with traces of nine rounded ribs somewhat crowded together ; if we allow two ribs for those not seen at the fracture and four at the apex, the total number of ribs will be in the neighbourhood of twenty-five. The remains of the test show the type of sculpture, which consists of minute tubercles, arranged more or less in lines that cross the ribs at an angle of about 45°.

This linear arrangement may be due to molecular movement, of which there are signs in the surrounding rock. It, however, recalls the " cancellated ornament " described by Matthew (1890, p. 133), and under appropriate lighting it gives the appearance of a pitted surface, which he also mentions.

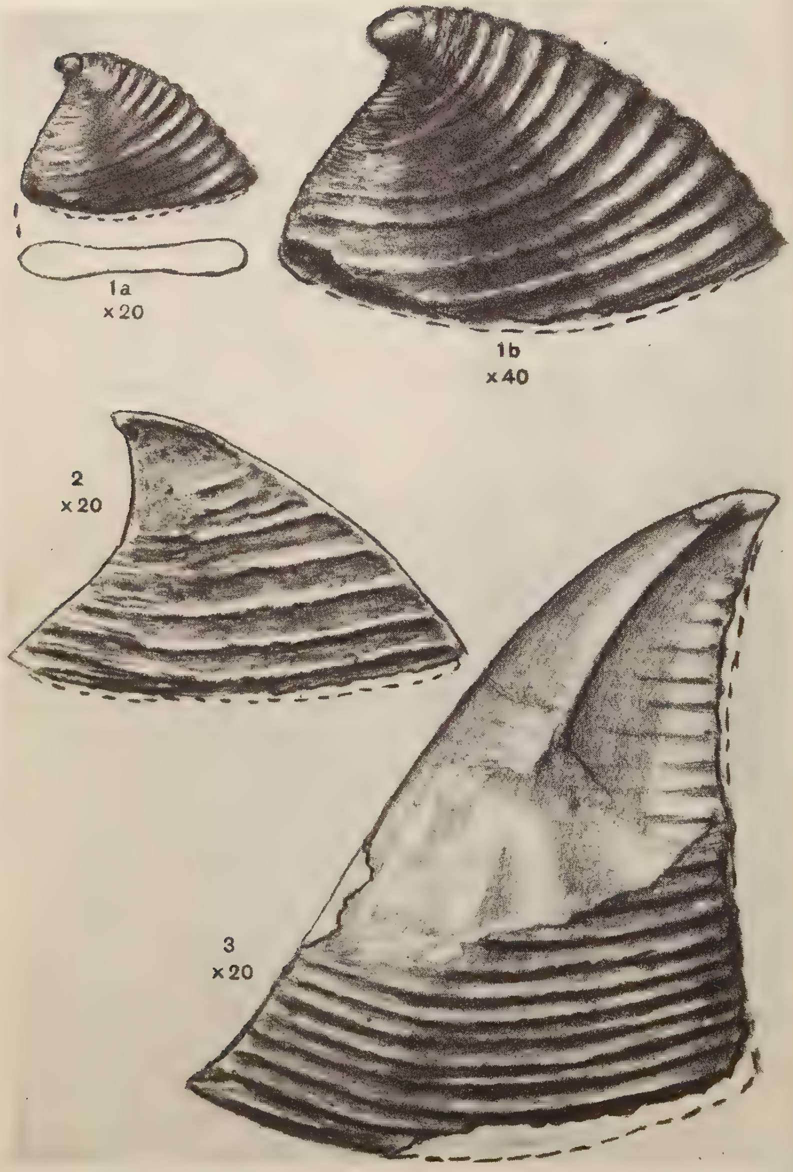
No trace of this arrangement could be detected in the holotype of *S. cornucopia.*

The apex of A 912 is occupied as to half its width by the pyramidal cast of the point.

Dimensions.—Length of aperture, about 4 mm. Height, about 4·20 mm.

PROVISIONAL DIAGNOSIS.

Before a definitive diagnosis of the genus can be written further specimens are required. The holotype does not exhibit the sculpture



STENOTHECA SALTER M.S. 1866.

of the test, nor the junction between the anterior margins of the sides, and the sides may not show the full natural convexity. In addition it is not clear whether the second and third specimens are varieties or distinct species.

The following is therefore put forward provisionally :—

Carapace, a small univalve, folded along the dorsal margin to form two nearly flat sides, each being subtriangular. Dorsal margin convex outwards, evenly rounded transversely, without keel, produced anteriorly to an apex more or less recurved over the anterior margin. Ventral margins free, gently convex downwards, or straight. Anterior margin almost straight from a notch or concave curve under the apex to the anterior angle. Aperture, elongate, oval or sub-oval, well-rounded posteriorly, widening towards the anterior end, *exact shape of anterior end unknown.* Surface of carapace corrugated with transverse concentric ribs, subparallel with the ventral curve and continuous over the dorsal margin, *whether these ribs are continuous or interrupted at the anterior margin is unknown.* A gradual and somewhat indefinite change in the character of the ribbing occurs near the apex, separating off an apical region from the remainder of the shell. Test thin, *sculpture unknown* in the genotype.

Genotype *Stenotheca cornucopia* Salter M.S.

Geological and Geographical Range.—*Middle Cambrian*: Menevian, South Wales. Acadian, Newfoundland.

Lower Cambrian (?) : Eastern North America ; Hérault, France.

The writer will be grateful for the loan of any further specimens of *Stenotheca* for study and comparison.

Address : Church Stretton, Shropshire.

REFERENCES.

Grabau, A. W. 1900. "Palaeontology of the Cambrian Basin of Boston": Occ. papers, *Boston Nat. Hist. Soc.*, iv, pt. iii.

—— and Shimer, H. W. 1909. "Gastropoda": *American Index Foss.*, i, 607.

—— 1910. "Phyllopoda": ibid., ii.

Hicks, H. 1872. "On some undescribed Fossils from the Menevian Group": *Quart. Journ. Geol. Soc.*, xxviii, 173.

Matthew, G. F. 1885. "Illustrations of the Faunas of the St. John Group": *Tr. R. Soc. Canada*, ii, sect. iv, 56.

—— 1890. "Illustrations of the Faunas of the St. John Group": ibid., viii, 132.

Walcott, C. D. 1886. "Second Contribution to the Studies of the Cambrian Faunas of North America": *U.S. Geol. Survey, Bull.* 30.

—— 1891. "The Fauna of the Lower Cambrian or Olenellus zone": *U.S. Geol. Survey, 10th Annual Report.*

EXPLANATION OF PLATE XXIII.

Stenotheca cornucopia Salter M.S.

FIG.

1*a*. Holotype, with outline of aperture, labelled "14, A 844 *Stenotheca* (*Hyolithes*) *cornucopia* (Salter). Menevian, Porth-y-rhaw, St. David's. Figured ? Hicks, *Quart. Journ. Geol. Soc.*, xxviii, 17, f. 12." × 20.

1*b*.—Same specimen. × 40.

Stenotheca spp.

2.—External impression of a right side (or interior) much flattened, A 279. × 20.

3.—A carapace, flattened and buckled, the lower part showing the exterior of the right side, test well preserved; the apical part, the interior of the left side, with a minute portion of the internal cast at the extreme apex and traces of the undulations; the intermediate, subtriangular space is occupied by further portions of the internal cast, roughly broken off at a very acute angle; A 912. × 20.

These last two specimens are attached to a tablet labelled "15, A 279 and A 912 *Stenotheca cornucopia* (Salter), Menevian, St. David's".

The Coastal Plateaux of South Wales.

By Kathleen L. Goskar, B.Sc., and A. E. Trueman, D.Sc.

I. Introduction.

ALONG the coast of South Wales is a series of plateaux, mostly at heights up to just over 400 feet above sea-level. They meet the coast in lines of cliffs, varied in character and often of great beauty. The most westerly area, in south and west Pembrokeshire, is the most perfectly developed, its level sky-line having been commented on by numerous writers (Dixon, 1921, p. 2; North, 1929, p. 23).[1] The Gower peninsula, which is detached from the other coastal plateaux by Carmarthen and Swansea Bays, shows similar features, as does also the Vale of Glamorgan which stretches from the shores of Swansea Bay almost to Cardiff.

Structurally the areas have much in common, for they all consist essentially of Upper Palaeozoic rocks (chiefly Old Red Sandstone and Carboniferous Limestone) folded into sharp anticlines and synclines which trend a little north of west. In the deep synclines Millstone Grit is sometimes preserved, and in Pembrokeshire the Coal Measures also form part of the plateau surface, while in the anticlines Silurian and older rocks form relatively small inliers. Over a large part of the Vale of Glamorgan, however, these Palaeozoic rocks are concealed under an almost horizontal cover of Mesozoic rocks (Keuper Marl, Rhaetic, and Lower Lias) which formerly extended over most of the areas which are considered here (Strahan, 1907, p. 2; North, 1929, pp. 23, 26; Trueman, 1924, p. 300).

In the Vale of Glamorgan the unconformable relation between the Mesozoic and Palaeozoic rocks is well displayed, the plane of unconformity in many places being obviously a wave-cut platform, and frequently, as at Barry, showing a terraced form (Cox, Sibly, and Trueman, 1920, p. 205; Trueman, 1922, p. 260). It has appeared that the removal from this area of the relatively soft Mesozoic cover would expose a smooth, but gently terraced surface truncating the complex structures of the Palaeozoic rocks. Consequently it has been suggested that the plateau form of the Palaeozoic areas of the Vale of Glamorgan, Gower, and south Pembrokeshire is largely due to the erosion of early Mesozoic times (Strahan, 1907, p. 2).

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[1] See list of References at end of article.

On the other hand these coastal plateaux resemble in many respects those plateaux in other parts of Britain which have been attributed to marine erosion during the subsidence of Pliocene times (Dewey, 1918, p. 156 ; Greenly, 1919, pp. 783-5). In the case of the plateau of south Cornwall it can hardly be suggested that marine erosion in the early Mesozoic has influenced the present form. Although in South Wales there is no direct evidence to be derived from deposits of Pliocene age (Dixon, 1921, p. 170), the possibility that the plateau in question may be due partly to Pliocene erosion has not been overlooked (Cox, 1920, p. 253 ; Dixon, 1921, pp. 2 and 170 ; North, 1929, p. 34 ; George, 1933, p. 192).

Thus, though it is generally considered that these plateaux were formed by uplift of a plain of marine erosion, such differences of opinion as exist regarding their origin are chiefly concerned with the relative importance of the Pliocene and early Mesozoic erosions. It is, of course, admitted that the Palaeozoic rocks underwent very considerable denudation in pre-Triassic and early Mesozoic times, but while some regard the present form as mainly due to Tertiary erosion others consider that this latter merely touched up an older feature (Dixon, 1921, p. 162 ; O. T. Jones, 1930, p. 162).

II. METHODS OF INVESTIGATION.

In addition to the study of these features in the field, further investigations of the topography of the plateaux has been attempted. Use has been made of the method devised by Barrell for constructing "projected profiles" (1920, p. 243) and of superposed and transparency profiles (Fridley, 1929, p. 117, footnote 2 ; Fridley and Nölting, 1931, p. 750). Various modifications of these methods have also been applied. So far as the writers are aware, none of these methods have been used hitherto in the investigation of British physiographical problems, apart from a tentative application of Barrell's method by Mr. J. Challinor.

The method of constructing projected profiles is essentially as follows. An area of country is selected on a contoured map of suitable scale ; in the present investigation the 1 in. "Popular" maps of the Ordnance Survey have been mostly used. One edge of the area is placed parallel to the edge of a drawing board, and a cross section is drawn along that line. By means of a T-square all elevations higher than those on the base line in a direction at right angles to it are added in the profile, the higher hills naturally obscuring the smaller elevations behind. The resulting profile gives an extended view of the topography and shows more clearly than a simple section the form of the ground represented. This is particularly the case

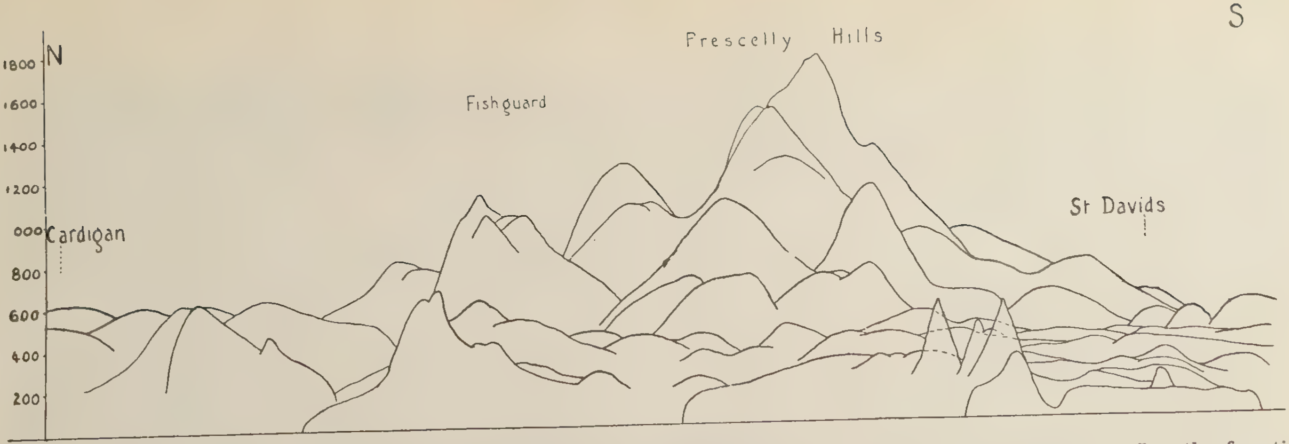

FIG. 1.—A projected profile of north-west Pembrokeshire and the adjacent parts of Cardiganshire, looking east. Length of section about 14 miles.

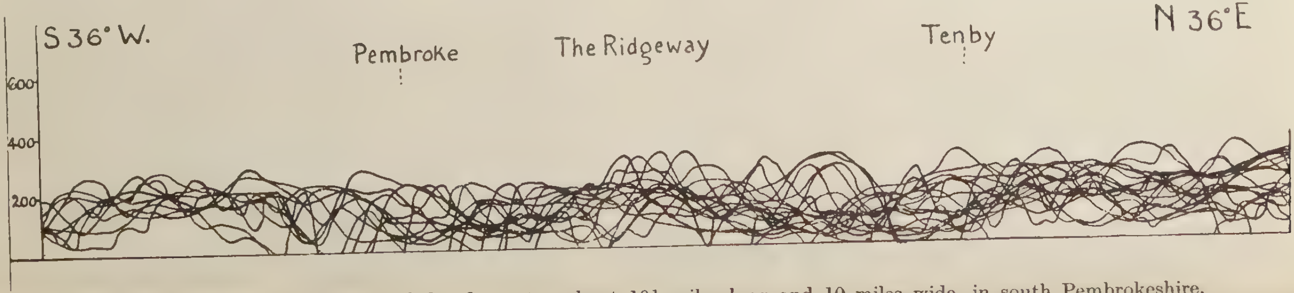

FIG. 2.—Superposed profiles of a belt of country about $10\frac{1}{2}$ miles long and 10 miles wide, in south Pembrokeshire.

when a section is drawn across a plateau which is considerably dissected. Moreover such a profile is to be preferred to a projection which merely shows the sky-line, as it gives the form of any features lower than the sky-line.

Numerous projected profiles have been constructed for different parts of the plateaux, using different base lines; that shown in Fig. 1 illustrates the general character of the results. In this case the area selected is north-west Pembrokeshire and the adjacent parts of Cardiganshire, which is viewed from a north-south base line running in the sea west of St. Davids. The area projected extends eastwards for some thirty miles, but only part of this distant landscape is represented, much of it being concealed by the nearer hills.

The methods of constructing profile sections along parallel lines at regular intervals and of transferring them to glass sheets, as used by Fridley, was modified by the use of tracing paper, a somewhat similar result being obtained by superposing a number of profiles on a single sheet. According to the nature of the topography to be represented, the number of sections varies from ten to twenty, a suitable distance between them in many cases being half an inch on a 1 in. map. This method gives a less impressive picture of the relief than that obtained by projected profiles, but it has the advantage of treating an area as if it were transparent, and of showing the presence of features which would be hidden by higher elevations in Barrell's method (Fig. 2). In this method, also, it has been found advantageous to draw several groups of sections for each area, using different directions.

It is necessary to use some caution in interpreting the results of such superposed sections. For example, a series of sections drawn obliquely across an escarpment which has a fairly level crest may give the impression of a number of hills reaching a similar height. Further evidence of a plateau surface must of course be found in such a case.

In both types of representation an attempt has also been made to correlate some geological data with the relief by using different types of line to indicate parts of the surface which are made up of various formations. Examples of these are shown in Figs. 3 and 4 and are discussed below.

III. The Topography of the Coastal Plateaux.

As has already been noted, there is considerable similarity among the three coastal areas, but as they each have some peculiarities, it will be useful to describe the results obtained in each.

1. *Pembrokeshire.*

In Pembrokeshire the plateau is remarkably even, there being no hills above 400 feet in height, except in the north and east of the county. In the north the Prescelly Hills rise sharply from the plateau, while several smaller hills also formed by intrusive rocks are seen to the west at St. David's Head, Pen Berry, and Carn Llidi. South-east of the Prescelly Hills the higher ground at about 600 feet extends to the neighbourhood of Whitland.

The larger part of the county is distinctly simple in relief. Although there is some indication of " grain " following the strike of the rocks, the shales in the anticlines and synclines being frequently reduced below the level of the plateau (Dixon, 1921, p. 3), the structure on the whole has little effect on the relief. Carboniferous Limestone forms much of the lower ground in the extreme south, but the height of the plateau surface is not controlled, in the main, by the outcrops of the various rocks, for this surface cuts across hard and soft rocks alike, including rocks ranging from the Ordovician to the Coal Measures (Fig. 4).

In north Pembrokeshire, the surface is seen to rise gradually from about 200 feet in the neighbourhood of St. Davids to just over 400 feet in the area between Llanriar and Haycastle, and extending for a couple of miles, at that height, to the east, before rising rather irregularly in this area to the Prescelly Hills. Evidence of a further area at 400 feet is seen in the Cardigan coastal area (Fig. 1).

Much of the area in south Pembrokeshire, mainly that part north-west and south of Milford Haven, lies at about 200 feet. The surface rises gently north-eastwards to a fairly considerable area between 300–350 feet and to 400 feet in the neighbourhood of Narberth, Whitland, and Ludchurch (Fig. 2). The Ridgeway Conglomerate forms a well-marked feature rising out of the 200 ft. platform.

Towards the coast at Angle, Bosherston, and Marloes the surface falls gradually to about 150 feet. This gradual slope seawards is to be expected if this surface was formed by uplift of a plain of marine erosion.

Evidence for a further level at approximately 600 feet is seen in the area north of the Prescelly Hills and extending into Cardiganshire (Fig. 1). This is a very well marked area ; further evidence of a similar area is seen in the region north and south of Whitland. The northern area is of Ordovician and Silurian rocks, while that to the south is of Old Red Sandstone. It is noticeable too that Carn Llidi, Pen Berry, and Garn Fawr and Garn Boch, near Strumble, also reach just over 600 feet.

2. *Gower.*

In Gower the plateau surface is also remarkably even, save for lower areas corresponding to synclines which include the softer shales of the Millstone Grit as at Oxwich and Port Eynon, and the prominent small hills composed mainly of the tough conglomerate of the Old Red Sandstone. All of these latter rise to about 600 feet and compare with Pen Berry, Carn Llidi, etc., reaching the same height in Pembrokeshire.

The remainder of Gower shows plateau features similar to those of Pembrokeshire, most of the area being between 200–250 feet O.D. This platform is mainly of Carboniferous Limestone, but is frequently covered by Glacial deposits which are variable in thickness and in places " tend to mask the regularity of the original plateau surface " ; thus the mounds near Hangman's Cross, between Paviland and Hills, near Pitton and at Kittle Top, all of which exceed 300 feet in height, are to be ascribed in part at least to these glacial deposits (George, 1933, p. 199).

Clyne and Fairwood Commons reach a height of over 300 feet and are occupied by the outcrops of Millstone Grit and Coal Measure shales and to a large extent covered with glacial deposits, while in north-east Gower a number of hills also reach a height of over 300 feet, some of them rising fairly sharply from between 200–250 feet. These areas are at Cil Ifor Top, Prisk, Llethrid, Cae Cenwyn, while larger areas are seen north of Dunvant, south of Penclawdd, north of the Townhill-Hendrefoilan Ridge ; in west Gower a small area occurs at Ryers Down. Except for the latter, which is composed of Old Red Sandstone, these areas are of sandstone bands in the Millstone Grit and Lower Coal Series. In north Gower much of the area reaches 400 feet, as at Gelli Gros, Mynydd Bach Coed, near Three Crosses, and on Clyne Common. Except for about half the Clyne Common area, which is covered with Boulder Clay, these areas are mainly of Lower Coal Series, consisting of shales with a few sandstone bands.

The 200 ft. platform is well marked in Gower, especially along the coast and over most of west Gower. The surface rises in north-east Gower to 400 feet, where most of the area at that height is of Lower Coal Series, mainly shale, and may be comparable with the area at that height in Pembrokeshire. The surface rises less gradually in Gower to this height. Much of the area shows intermediate heights between 300–350 feet and though some parts rise quite gradually to 400 feet, other parts rise more irregularly owing to the more resistant nature of the sandstones of those areas. This, together with the fact that much of the area is covered with Boulder Clay, tends to mask the true nature of the plateau, but the relationship is probably much the same as in Pembrokeshire.

The 200 ft. platform, though very clearly defined, does not maintain an absolutely constant height over the whole area. Thus at Pwlldu the surface reaches 300 feet at the Headland, rising very gradually to this height from 200 feet in the neighbourhood of Penard.

On the other hand from Rhossili to Worm's Head, the surface falls from 200 feet to about 160 feet (George, 1932, p. 313 and fig. 29). This slight inclination is comparable to the similar inclination in south Pembrokeshire and may be due to the same cause, that is, the original slope of the surface as a plain of marine erosion.

3. *The Vale of Glamorgan.*

Save that much of the Vale is occupied by Mesozoic rocks (chiefly Lower Lias) whose horizontal bedding gives rise to cliffs of very different character from those of Gower and Pembrokeshire, the features in the main are similar.

The same plateau character is at once noticeable. A platform at 200–250 feet is well developed along the coastal belt (where the surface is largely of Lower Lias with small areas of Carboniferous Limestone) and in a rather more extensive tract to the east in the region of the Taff and Ely valleys. This platform rises gradually inland to about 350 feet. The surface cuts across Lower Lias, Trias, and Carboniferous Limestone.

To the north of the Vale much of the area reaches just over 400 feet. Part of this area is covered with Boulder Clay, but most of it is free of drift, and is occupied by outcrops of Coal Measures (Cefn Hirgoed, Cefn Cribwr, and south of Llanharan) and Carboniferous Limestone (St. Lythan's Down and south of Welsh St. Donats) with some Lias (also south of Welsh St. Donats) and Old Red Sandstone (south of Pentyrch). Mynydd y Forest, west of Ystradowen, and the area north of Welsh St. Donats are the main drift-covered areas, while further west the Boulder Clay rises to the edge of and thins off against the Carboniferous Limestone plateau of St. Nicholas. The highest point to which the drift reaches is 426 feet on St. Lythan's Down, most of which is Carboniferous Limestone (Cantrill, 1912, p. 77). This area at 400 feet appears to be a well marked platform (Fig. 3). The feature is seen fairly clearly from Swansea, being slightly above the level of the main part of the plateau, which slopes very gradually to the south.

In the Vale there is a general absence of the 600 ft. level recognized so widely in Pembrokeshire, though it may be represented in the hills north of Cardiff such as Garth Wood. Generally the coastal plateau rising to 400 feet extends to the slopes of the hills of the upland plateau which rise sharply to 800–1,000 feet.

The subsequent dissection appears to have been rather greater in the Vale than in Gower or Pembroke judging from the wider river valleys and the comparatively small remnants of plateau between (North, 1929, p. 36).

GENERAL CONSIDERATIONS.

A 200 ft. platform is widely recognized in Pembrokeshire, Gower, and the Vale of Glamorgan. Many areas at about 400 feet are found in all three regions, while the areas at 600 feet are confined mainly to Pembrokeshire.

It is interesting to note that from a study of base levels in the various rivers in South Wales, uplifts of approximately the same amounts as indicated by the platforms seem to have taken place.

Professor T. N. George has suggested that the widespread develop-

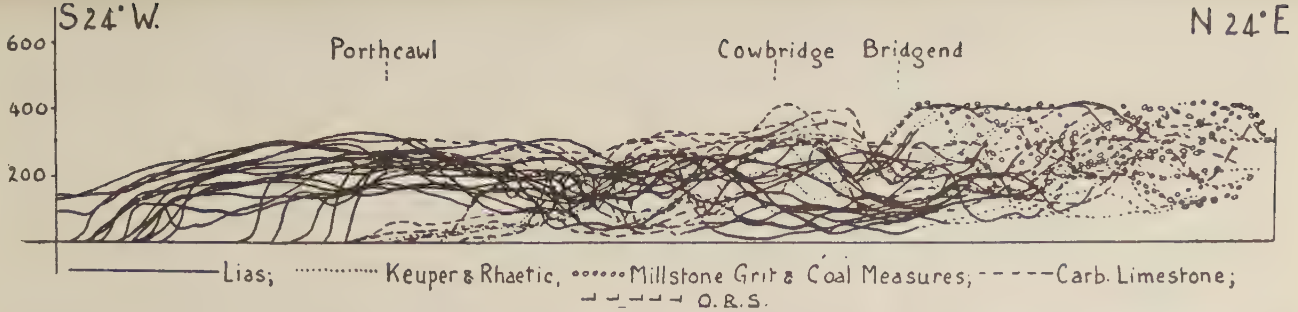

FIG. 3.—Superposed profiles showing the outcrops of the more important formations in a belt of country about 9 miles long and 12 miles wide in the Vale of Glamorgan.

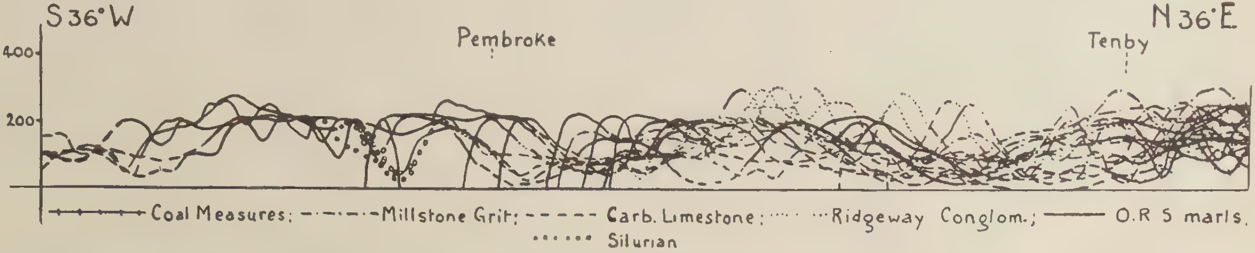

FIG. 4.—Superposed profiles showing the outcrops of the more important formations in a belt of country about 9 miles long and 8 miles wide in the south of Pembrokeshire.

ment of a platform at about 200 feet along the coast of various parts of South Wales might well be connected with the high level mature valleys which are about 200 feet above the present level of the Tawe (in discussion of R. O. Jones, 1931, p. 321). Professor O. T. Jones concluded that uplifts amounting to 400 feet and 580 feet have affected the Towy system (1924, p. 608).

While it is premature to link these levels with the platforms recognized in the South Wales coastal areas, there is further evidence in Britain of an uplift of 400 feet in Devon and North Wales (Dewey, 1918, p. 157) and in the London Basin (Wooldridge, 1928, p. 2), while Dr. Greenly discussed a level at 550 feet in Anglesey (1919, pp. 783, 785). There is also abundant evidence in many parts of Britain, notably in North Wales (Dewey, 1918, p. 156 ; Greenly, 1919, pp. 783, 785), south-west England (Jukes Brown, 1907, pp. 111, 119), and the London Basin (Wooldridge, 1928, p. 1) of a platform at a height of 200–250 feet O.D.

The existence of a well-marked base level at 200 feet in the London Basin implied, according to Wooldridge, the existence of some equivalent features elsewhere, though he considered that it might be obscured by extensive dissection and differential erosion. He attached a high degree of probability to the correlation of these various severed parts of this base level (1928, pp. 22, 23).

The amount of warping which has affected the plateaux in South Wales as a result of subsequent movement appears to be negligible. The movements indicated by raised beaches and submerged forests appear to have been regional and not local, and the amount of warping that has been demonstrated in these is practically nil (T. N. George, 1932, p. 296).

It appears that such a surface as that developed in the coastal areas in South Wales could only have been produced by erosion as the land was rising, the lower platforms having been cut so far as to remove all traces of a higher level at certain places, so that the lower platforms may adjoin the higher hills of the inland areas. Thus the almost complete absence of the 600 ft. platform east of Carmarthen leads to the coastal plateau at 400 feet abutting against the higher hills of the South Wales Coalfield.

Thus it follows that this topography cannot have resulted from the effects of the advancing Mesozoic waters. Post-Mesozoic erosion, presumably in Pliocene times, must have modified very considerably the surface produced in Mesozoic times. This later erosion appears also to have been more than a mere " touching-up " of the Mesozoic features.

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REFERENCES.

Barrell, J. (1920). " The Piedmont Terraces of the Northern Appalachians " : *American Journ. Sci.*, **4**, xliv, 242.

CANTRILL, T. C. (1912). In "Geology of the South Wales Coalfield. Part III: The Country around Cardiff": *Mem. Geol. Surv.*, 2nd ed.
CHALLINOR, J. (1929–1930). "The Hill-top Surface of North Cardiganshire": *Geography*, p. 652.
COX, A. H. (1920). In "Handbook to Cardiff and the Neighbourhood": *Brit. Assoc. Handbook* (Cardiff).
COX, A. H., SIBLY, T. F., and TRUEMAN, A. E. (1920). "Excursion to Cardiff": *Proc. Geol. Assoc.*, xxxi, 205.
DEWEY, H. (1918). "On the Origin of some Land-forms in Caernarvonshire, North Wales": GEOL. MAG., 145.
DIXON, E. E. L. (1921). "The Geology of the South Wales Coalfield. Pt. xiii: Pembroke and Tenby": *Mem. Geol. Surv.*
FRIDLEY, H. M. (1929). "Identification of Erosion Surfaces in South-Central New York: *Journ. Geol.*, xxxvii, 113.
FRIDLEY, H. M., and NÖLTING, J. P. (1931). "Peneplains of the Appalachian Plateau": ibid, xxxix, 749.
GEORGE, T. N. (1932). "The Quaternary Beaches of Gower": *Proc. Geol. Assoc.*, xliii, 291.
—— (1933). "The Coast of Gower": *Proc. Swansea Sci. and Field Nat. Soc.*, i, 192.
GREENLY, E. (1919). "The Geology of Anglesey": *Mem. Geol. Surv.*, vol. ii.
JONES, O. T. (1924). "The Upper Towy Drainage-System": *Quart. Journ. Geol. Soc.*, lxxx, 56.
—— (1930). "Some Episodes in the Geological History of the Bristol Channel Region": Pres. Add. Sect. C., *Rep. Brit. Assoc.* (Bristol), p. 57.
JONES, R. O. (1931). "The Development of the Tawe Drainage": *Proc. Geol. Assoc.*, xlii, 305.
JUKES-BROWNE, A. J. (1907). "The Age and Origin of the Plateaux around Torquay": *Quart. Journ. Geol. Soc.*, lxiii, 106.
NORTH, F. J. (1929). "The Evolution of the Bristol Channel, with special reference to the coast of South Wales": *Nat. Mus. Wales.*
STRAHAN, A. (1907). "The Geology of the South Wales Coalfield. Part VII: The Country around Swansea": *Mem. Geol. Surv.*
TRUEMAN, A. E. (1922). "The Liassic Rocks of Glamorgan": *Proc. Geol. Assoc.*, xxxiii, 245.
—— (1924). "The Geology of the Swansea District": ibid., xxxv, 283.
WOOLDRIDGE, S. W. (1928). "The 200-foot Platform in the London Basin": ibid., xxxix, 1.

REVIEW.

GEOLOGY OF CORAL REEFS. By DR. PH. H. KUENEN. Wetenschappelijke Uitkomsten der Snellius-Expeditie, vol. v, pt. 2. Utrecht, 1933. Quarto, 125 pages, 106 text figures, and 11 plates.

OWING to exceptionally favourable conditions of work, Dr. Kuenen has been able to accumulate a surprisingly large volume of interesting facts concerning the coral reefs which he visited in the comparatively short time at his disposal in the course of the Snellius Expedition to the Dutch East Indies. Great care has been taken to keep tentative theoretical conclusions and speculations separate from the observed facts upon which they are based, and the usefulness of the report to a student of coral reefs is very much enhanced by this segregation. Naturally, the detailed description of the islands and reefs examined forms the most valuable part of the work, but the later chapters, in which the results are discussed in their relation to some of the broader problems of coral reef geology, are of more general interest.

The formation of atolls has received considerable attention. The majority of such reefs stand on shoal-water platforms, which rise abruptly from submarine ridges " as if they had grown onto these as barnacles ". Profiles from shoal water down to the surfaces of the deeply submerged plateaux and ridges show steep upper slopes, often much steeper than the maximum angle of repose for underwater screes of either coral debris or volcanic material. Off many of the atolls, these precipitous slopes, assumed to be formed directly by upward coral growth, descend considerably below the lowest stand which can reasonably be claimed for sea-level in Pleistocene times. For this reason, amongst many others, Dr. Kuenen believes that the banks on which the atolls stand were formed during a prolonged subsidence of the sea floor throughout later Tertiary and Pleistocene times. Low level abrasion, consequent upon depression of sea-level during the Pleistocene glaciations, is believed to have done nothing more than modify the upper parts of well-developed atolls and other reef structures, which had already reached a considerable thickness.

The recent eustatic fall of 5 metres in sea-level, which has left its traces on so many shore lines, was also investigated in detail. Dr. Kuenen finds that this fall took place in three distinct stages, represented by benches at 4–5 m., 1½–2 m., and ½–1 m. ; the recognition of these stages is of considerable interest, for the otherwise anomalous levels of raised strand lines in other areas appear to fit readily into this scheme.

The numerous sketches, sections, and sketch-maps with which the report is generously illustrated add much to the clarity of the text.

M. B.

CORRESPONDENCE.

THE ORIGIN OF IGNEOUS ROCKS.

SIR,—As the result of field and petrological study of the igneous rocks of Caledonian age in the Newry Complex and in Argyllshire, combined with a comparative study of other areas, it is now possible to throw light on the origin of igneous rocks in orogenic regions. A brief summary of the conclusions, the full details of which will be published shortly, are as follows.

The parent magmas are ultrabasic and can frequently be shown to be represented by biotite-pyroxenite, hornblendite, and allied rocks. The ultrabasic magmas, which were rich in volatiles, rose by soaking and shouldering stress, and at the same time gave off emanations rich in alkalies. In consequence a zone of alkali enrichment preceded the advancing magma, and it can usually be demonstrated that soda travelled more rapidly and farther than potash. As the result of this alkali enrichment, the invaded sediments (including metamorphic varieties) are felspathized, quartz in particular being commonly converted to soda-potash felspar. To the felspathization of country rocks, together with an accompanying seeping in of ultrabasic magma, the rocks of batholithic intrusions are to be attributed.

By the combination of the two processes, felspathization and magmatic soaking, biotite-pyroxenite and allied ultrabasic magmas give rise, on invading aluminous sediments, to the series shonkinite–monzonite–syenite. The shonkinite consists of a small proportion of felspathized sediments and a high proportion of magma, whilst the syenite is in the main sediments enriched in alkalies. Monzonite represents a gradation between these two extremes. Hornblendite magma under similar circumstances gives rise to a parallel series appinite–diorite–plagioclasite. All gradations can be found between biotite-pyroxenite and hornblendite, and corresponding gradations are to be found between the two hybrid series to which they give rise. Kentallenite, in particular, is a connecting link between appinite and shonkinite, and is the result of the invasion of aluminous sediments by a magma representing biotite-hornblendite in composition.

These rocks, which frequently occur as marginal zones in "granite" batholiths and as xenoliths in the "granite", are developed in three different ways :—

1. By actual soaking of ultrabasic magma into country rocks which have already been enriched in alkalies by a vanguard of magmatic emanations. By this process the rock types mentioned above are developed in situ.

2. From magmas produced by the operation in depth of a process similar to that of case 1.

3. By the invasion of the ultrabasic rocks or magmas or their hybrid derivatives by a felspathic magma, such as plauenite, soda-syenite, or plagioclasite, each of which is attributed to enrichment of sediments in alkalies of ultrabasic origin. Augite-biotite-diorite, biotite-gabbro, and hornblende-gabbro may arise in this way by admixture of biotite-pyroxenite or hornblendite and plagioclasite.

When quartzite is invaded by biotite-pyroxenite or hornblendite magma, two immiscible magmas result. In the case of hornblendite the resulting magmas are appinite and soda-syenite, whilst in the case of biotite-pyroxenite and allied types the resulting magmas are shonkinite and syenite of Plauen type.

The acid rocks, which are generally dominant in batholiths, are formed in the following ways :—

1. Enrichment of siliceous sediments (including metamorphic derivatives) in alkalies of ultrabasic origin.

2. The soaking of one of the felspathic magmas, plagioclasite, syenite, or soda-syenite, into siliceous sediments or their metamorphic derivatives.

3. By the soaking of one of the hybrid types of intermediate composition into siliceous sedimentary or metamorphic rocks with an accompanying enrichment of the invaded rocks in alkalies.

These three processes may take place in situ, in which case the " granite " is usually porphyritic, or in depth. In either case there may be partial fusion of the sediments. The Newry Igneous Complex, for example, is margined by a zone of partial fusion at its eastern end.

The characteristic hypabyssal rocks of orogenic regions, which include the lamprophyres, porphyries, porphyrites, and aplites, are explained in a similar manner. Minette and kersantite are the hypabyssal representatives of shonkinite, kentallenite, and augite-biotite-diorite, whilst vogesite and spessartite correspond to the appinites. Many aplitic rocks represent siliceous sediments which were only partially fused and enriched in alkalies and, in consequence, they retain a granular hornfels texture.

This scheme of petrogenesis provides a common explanation for the igneous rocks of orogenic regions of all ages; explains the frequent association of rocks of Atlantic and Pacific type; and accounts for the vanished sediments in batholithic regions.

Doris L. Reynolds.

The Science Laboratories,
The University,
Durham.
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